DIVERSITY, ECOLOGY, AND CONSERVATION OF BIRD COMMUNITIES OF *POLYLEPIS* WOODLANDS IN THE NORTHERN ANDES OF PERU

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science

by

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May 2016

ABSTRACT

Montane birds are sensitive to a wide variety of human activities, among which climate change is of special concern. Among the most diverse and specialized montane bird communities is that of *Polylepis* forests in the High Andes (> 3,500 m). Unfortunately, the ecology of birds associated with *Polylepis* forest, especially endemic and threatened species, remains poorly known. This gap in knowledge is worrisome given that climate models project that future conditions will be warmer and drier, which could negatively impact many of the species in this ecosystem. This research investigated patterns of species richness and bird-habitat relationships across along an elevational gradient (~3,300 – 4,700 m) and across wet-dry seasons in five valleys of Huascaran National Park within the Cordillera Blanca range of Peru.

In 2014-2015, birds and habitat characteristics were surveyed at 130 point count locations and systematically observed between points during wet and dry seasons. I calculated observed and expected (Abundance-Coverage Estimator) species richness for valleys, seasons, and within 100-m elevational bands. Estimates of species richness exceed those of previous studies in *Polylepis* forest along the Andes. There was a consistent pattern of greater species richness in wet compared to dry seasons, though the pattern declined in strength with elevation. Species richness peaked at mid-elevations (~4,000 m) for the overall bird community, while the greatest number of endemics and threatened birds were found at ~4,300 m *Polylepis* forest was a particularly important habitat that seemed to promote diversity and might provide an important refuge for species in the face of climate change.

Species-habitat associations of 50 species of birds, including 13 of conservation priority, showed that birds were associated with four habitat types. Four species of conservation priority (*Oreomanes fraseri, Poospiza alticola, Atlapetes rufigenis,* and *Cranioleuca baroni*) were strongly associated with structural characteristics of large forest patches (~10 ha) dominated by *P. sericea* (<3,800 m), whereas another four (*Anairetes alpinus, Leptasthenura yanacensis, Zaratornis stresemanii,* and *Scytalopus affinis*) were associated with less disturbed forests of *P. weberbaueri* (> 4,200 m). Open Puna and shrubland habitats also maintained a high number of most common species.

These results suggest that, although declines in species richness during dry seasons may negatively affect certain species under the projected warmer and drier conditions for this region, *Polylepis* forest fragments might provide important refuge or buffering against future changes in climate. Moreover, in addition to conserving and using large (>10 ha) *P. sericea* forests at lower elevations as the cornerstone for maintaining bird diversity, any high elevation (> 4,200 m) relicts of *P. weberbaueri*, irrespective of size, should be prioritized for conservation in order to protect key habitat of threatened avian species in Cordillera Blanca. Population studies of priority bird species, combined with coordinated monitoring, will provide important insights into the response of bird populations to human activities and climatic changes and help to inform conservation of High Andean biological diversity.

BIOGRAPHICAL SKETCH

Steven C. Sevillano Ríos was born in the city of Huaraz, a city within the Cordillera Blanca of Peru, where, from an early age, he was in close contact with nature. Steven's interest in nature and biology was kindled by his parents, Cristian Sevillano and Nini Rios, who shared their sightseeing tours and traveled frequently with him and his two brothers, Sebastian and Adrian. During his last years at school, Steven met Professor Nini Sanchez, a true pedagogue of yore, which few are now, who sparked his great interest in the natural sciences and reaffirmed his wish to study biology.

Steven studied biology at Cayetano Heredia University in Lima, where his advisor, Dr. Armando Valdés-Velásques introduced him to the scientific world of ecology. Twice during his college career, Steven was forced to interrupt his studies in order to take care of family affairs - for rheumatic fever affecting his father in March of 2002 and his mother's diagnosis with breast cancer in 2006. Thankfully, both recovered well and despite these interruptions, Steven completed his bachelor's in biology in 2007.

Steven always hoped that he would one day apply his knowledge to his birthplace, Cordillera Blanca and mountains in general. Thus, after finishing his BS degree, he conducted his undergrad thesis research in Huascarán National Park, working with the incredible *Polylepis* forests and its birds. Steven also developed several projects through the Mountain Institute in order to disseminate knowledge about the goods and services provided by *Polylepis* forests and their potential for sustainable use. After publishing the results of his research, Steven frequently gave talks at conferences and workshops about *Polylepis*, and he helped to create a communal conservation area in the Cordillera Huayhuash.

Soon thereafter, Steven moved to southern Peru in order to explore new opportunities. Working on Manu National Park, Tambopata National Park and Bahuaja Sonene National Park, three of the most biodiverse areas of the world provided Steven with the incredible opportunity to learn from nature, especially from birds, and to realize that he could expand the ecological knowledge of poorly understood natural systems. At Wayquecha Biological Station, he learned from Dr. Huw Lloyd, and several graduate students that were conducting field work. During his time with Wildlife Conservation Society's (WCS) in the Alto Tambopata Landscape Project, he worked with coffee farmers and local people to facilitate conservation of these natural areas. He also co-coordinated two rapid biological assessments in very remote Amazon areas. While there, Steven saw first-hand the massive destruction of biological richness by illegal mining, unrestricted burning and the use of land for cultivation of illegal crops.

In 2013, Steven received a Fulbright Scholarship to start his Master of Science program in Natural Resources at Cornell University, where he was advised by Dr. Amanda Rodewald. In 2016, Steven transitioned to the doctoral program at Cornell, thanks to a fellowship from the Peruvian CONCYTEC. Steven expects to return to Peru after this studies and apply this experience and knowledge towards the conservation and scientific understanding of his amazing but still poorly known country. He also expects to strengthen the link between Peru and Cornell.

I dedicate this work to the memory of my loving grandparents,

Mr. Felix Sevillano (Jan 2016) and Ms. Herlinda Montañez de Sevillano (Dec 2014).

ACKNOWLEDGMENTS

I wish to thank my advisor, Amanda Rodewald, who from the outset of our discussions showed a great interest in my ideas of study and has done everything to make me a member of the Cornelian community and part of the Lab of Ornithology. Thank you for supporting and guiding me and facilitating many processes of my research, like funding for the field work expeditions. I also thank to my committee members: Stephen Morreale for accepting this challenge and for the critical and intensive discussions that helped improve my research and Eduardo Iñigo-Elias for his insights and support on improving our cooperative work throughout Latin America.

I thank the members of the Conservation Science and Bird Population Studies Lab at Cornell Lab of Ornithology. To André Dhondt, Ken Rosenberg, Viviana Ruiz-Gutierrez, Eric Wood, Peter Arcese, Wesley Hochachka for their valuable comments and constructive criticism that helped expand my horizons of ecological understanding. To my lab friends Gemara Gifford, Ruth Bennett, Darin McNeil, Gerardo Soto, Rose Swift, Bryant Dossman, with whom the freezing Ithaca life became much more tropical. To several members of the Department of Natural Resources, thanks to Ted Lawrence, Pepe Casis, Graciela Reyes, Maria Jose Carreras, Manuel Berrio, Justin Proctor, James Lassoie, Martin Zorrilla, and Katherine Kaplan who, through our meetings in the Latin America Conservation group, gave me ideas about how to communicate my study results to different audiences.

I want to thank Irby Lovette, who facilitated the participation of undergraduates in my research. Thanks to the Athena Grant, the Bergstrom Award and Fulbright Scholarship, without whose funding the research would not have been possible. Thank you very much to Jessica Pisconte, Nathaniel Young, Rosaura Watanabe, Nicolas Mamani as the core field crew for the data gathering and the enormous amount of time "listening to my lovely

voice". I owe you more meetings in the Tambo! Thanks to the staff of Huascaran National Park, to Ricardo Jesús Gómez, Selwyn Valverde, Oswaldo Gonzales, Martin Salvador, and the rangers who from the beginning gave me the resources to develop the research. To the student interns at the HNP, Dennis Rojas, Ingrid Peña, Fiorella Bernales, Gabriela Salazar. Thanks to Austen and Henney Sullivan for his help and to Jack Valderrama (MAGSER Rent a Car) for the transport services. To the Mountain Institute, under the direction of Dr. Jorge Recharte. To Manuel Plenge for the firsthand literature and to Katty Sandoval for the great illustrations of the Ash-breasted Tit-tyrant and the Giant Conebill.

I would like to thank my family, especially my mother Nini Ríos and my father Cristian Sevillano, who opened the possibility of discovering “La Chacra”, nature, and now, enjoying our adventures in the mountains with me. Thanks for the great support of the whole crew at home! Thanks to my brothers Sebastian and Adrian Sevillano who accompanied me to these mountains with unforgettable moments. To my grandparents Felix Sevillano (1924 -2016); Herlinda Sevillano Montañez (1931 - 2014), Dr. Arnulfo Ríos de la Cruz (1921 - 2008) and Emperatriz Ríos Salcedo (1925-2007).

Finally, I want to thank Laura V. Morales, for her love and support throughout my research. For she has been next to me, despite the distance, from our earliest moments at Wayquecha, the high peaks of Huaraz and cold mornings of Ithaca, and discovering together the beauty of love. Thanks for your sharp criticism and long hours of scientific discussion that helped improve not only manuscripts but our relationship. You have been an inspiration in my life; I love you.

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CHAPTER I

INTRODUCTION

Montane systems are recognized as one of the most important regions on Earth (UN 1992; 1998; Beniston 2003, IUCN 2015). Mountains represent from 20% to 25% of terrestrial surface (Kapos *et al.,* 2000; La Sorte and Jetz, 2010), and provide a variety of services and resources to half of humanity (Beniston, 2003), including water supply through the global river systems originating in the mountains. Moreover, they are also recognized as global centers of biodiversity (Spehn *et al.,* 2010), due to the high degree of endemism and species richness that are restricted to specific mountain ecosystems (Gareca *et al.,* 2010). However, most mountain systems around the world face serious threats due to land use change from a wide variety of human activities (e.g., grazing and timber harvest), and more recently, climate change (Pounds *et al.,* 1999; Beniston, 2003; Şekercioğlu *et al.,* 2008; Gasner *et al.,* 2010; Şekercioğlu *et al.,* 2012).

Birds are recognized as one of the best indicators of habitat disturbance and they have been used as a proxy to model the consequences of human activities on biodiversity (Şekercioğlu at al., 2012). Numbers of many species track changes in habitat and environmental conditions (Loiselle and Blake, 1991), and recently, an increasing number of studies have shown that some birds can respond rapidly to climate change (e.g. Cresswell and McCleary, 2003; Charmantier *et al.,* 2008). Whilst generalist species with high dispersal abilities should have more capacity to respond to rapid environmental change, species with poor dispersal ability, specialized ecological niches and small population sizes will likely face more severe challenges (Huntly *et al.,* 2006).

Montane birds may be particularly affected by the variety of threats around the globe, given that many of these species are endemic and may have limited dispersal ability (Loiselle and Blake, 1991; Levey and Stiles, 1992; La Sorte and Jetz, 2010), high levels of ecological specialization (Fjeldså, 1993), and small population sizes (Crick, 2004). In addition, the topography of mountains tend to isolate populations and restrict them to relatively small areas and, thus, small population sizes. Consequently, many montane species are adapted to inhabit a narrow set of habitat and environmental conditions with a delicate ecological equilibrium (Beniston, 2003; Tse-ring *et al.*, 2010;). It is not surprising then, that the majority of centers of endemism and diversity hotspots, along with many globally threatened or endangered species, are located in mountain systems around the world (Myers *et al.*, 2000; IUCN, 2015).

Some of the most vulnerable mountain ecosystems are located at the highest elevations of the tropical mountains (Young *et al.*, 2011). One particular ecosystem, nested on the humid and dry Puna, is the *Polylepis* forest (Kessler, 2006; Young *et al.*, 2011). Dominated by trees of the *Polylepis* genus (Rosacea), *Polylepis* forests are recognized as one of the most important habitats and refugees for avian diversity throughout the High Andes (> 3,500 m) (Fjeldså, 2002; Kessler, 2006; Lloyd 2008 a, b, c). Extending up to 5,200 m, they represent one of the upper altitudinal limits of forests in the world (Gareca, 2010), where several endemic and highly specialized bird species match their distributions with the isolated and patchy distribution of *Polylepis* (Fjeldså and Krabbe, 1990; Fjeldså *et al.*, 1999; Fjeldså, 2002). These birds, with limited dispersal ability (Lloyd and Marsden, 2011), high levels of ecological specialization (Servat, 2006; Lloyd, 2008b), and small population sizes (Lloyd 2008a), are particularly sensitive and vulnerable to several human activities, including climate change (Young et al, 2006; Şekercioğlu *et al.,* 2012).

Andean ecosystems, in particular, have been subject to a wide range of anthropogenic threats that have destroyed, fragmented, and degraded several of their intrinsic natural characteristics (Simpson 1979). According to some studies, fire (Renison *et al.*, 2002), firewood collection (Fjeldså, 1993), and browsing by livestock (Teich et al, 2005; Cierjacks *et al.*, 2008) are among the activities most responsible for poor *Polylepis* forest regeneration and fragmentation (Kessler, 2002; 2006). Fjeldså and Kessler (2004) conclude that due to these human activities, the *Polylepis* forest at that time had been reduced by 97-99% of its potential distribution on the eastern Andean slopes of Peru and Bolivia. Purcell and Brelsford (2004) found that the 87% of the Bolivian *Polylepis* woodlands of the eastern Cordillera Real valleys were destroyed in only 12 years, due the expansion of roads and mining projects. Collectively, these alterations have made *Polylepis* forests one of the most endangered Andean ecosystems (IUCN Red List, 2015); and although several projects are currently working for their restoration and conservation (by NGOs like The Mountain Intitute, ECOAN in Peru), our understanding of the ecological consequences of these human activities remains unclear, thereby limiting the potential effectiveness of conservation efforts.

One of the major remaining areas of *Polylepis* forests along the Andes is Cordillera Blanca, Ancash, Peru. This area, protected for about 40 years by Huascaran National Park and Biosphere Reserve, harbors the highest concentrations of *Polylepis sericea* and *P. weberbaueri* along their distribution (Mendoza and Cano, 2012; Zutta et al. 2012), with at least 14 bird species of conservation concern, including endemic, restricted range, and threatened species (IUCN Red List, 2015). Here, effects of climate change are already evident with respect to glaciers and water availability, but no research has assessed the consequences to biodiversity. My research aimed to provide a foundation for understanding

1) temporal and spatial variation in species richness patterns and 2) species-habitat associations of the *Polylepis* bird community exhibited along one of the highest elevation gradients in the Andes.

THESIS FORMAT

My thesis consists of three main chapters, each representing a manuscript that will be submitted for publication. Chapter II provides a review of the ecology and conservation of the *Polylepis* bird community. Although several bird species of conservation priority inhabit *Polylepis* woodlands, our understanding of their ecology is still under development and is only known from relatively few studies (Herzog *et al.*, 2002; Herzog *et al.*, 2003; Cahill and Matthysen, 2007; Cahill *et al.*, 2008; Lloyd 2008a, b, c; Lloyd and Marsden, 2008; Matthysen, 2008; Bellis *et al.*, 2009). Restoration and conservation efforts of *Polylepis* forest however, should incorporate this ecological knowledge in order to expand the benefits to the whole ecosystem, using birds as a tool to measure success.

Chapter III describes temporal (wet/dry seasonality) and spatial (along elevation) variation in species richness within five glacial valleys of Cordillera Blanca. Because future climate in the Tropical Andes is predicted to be warmer and drier (Urrutia and Vuille, 2009; Seiler *et al.*, 2013), understanding how species richness changes across wet and dry seasons might provide insight into avian responses to future conditions. Although species richness is predicted to decline with increasing temperatures and decreasing precipitation (Böhning-Gaese and Lemoine, 2006), high elevation ecosystems could buffer the effects of climatic change by providing a more humid and stable environment (Peterson *et al.*, 2003).

In Chapter IV, I describe the associations between birds and macro- and micro-habitat characteristics along an elevation gradient. Habitat associations of *Polylepis* birds

have been investigated only in recent studies in Cuzco, Bolivia and Ecuador (Cahill and Matthysen, 2007; Lloyd, 2008 a, b, c; Tinoco *et al.*, 2014), and the ecology of many endemics remains poorly known. Understanding species-habitat relationships will improve our capacity to predict the consequences of human activities and climate change for this sensitive and threatened bird community.

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CHAPTER II

ECOLOGY AND CONSERVATION OF *POLYLEPIS* WOODLAND BIRDS: A REVIEW

INTRODUCTION

Polylepis woodlands are forests dominated by trees and shrubs of the *Polylepis* genus (Rosacea) distributed along the Andes and Sierras de Cordoba (Argentina) (Kessler 1995a, Kessler and Schmidt-Lebuhn, 2006). They represent the upper altitudinal limit of forests in the world (Purcell et al, 2004; Hoch and Körner, 2005), and are recognized as hotspots of avian endemism and diversity (Fjeldså, 2002). These forests were probably a once widespread ecosystem along the Andes, but massive destruction by human activities, like fire and cattle, resulted in the patchy and fragmented distribution that *Polylepis* forests exhibit today (Ellenberg, 1958). However, others argue that the current *Polylepis* distribution is a natural characteristic due to microclimatic stress (Simpson, 1979; 1986), and that the constitutive species (e.g., plant and birds) have developed different strategies to survive in this landscape configuration (Vuilleumier, 1984). Irrespective of its historic distribution, *Polylepis* forests are now among the most threatened ecosystems of the Tropical Andes (Fjeldså, 2002, Stotz *et al.,* 1996) and support several bird species of conservation concern (IUCN 2105), with population declines primarily attributed to habitat loss and fragmentation (Fjeldså, 2002; Servat, 2006; Tinoco *et al.*, 2013). Here, I review current knowledge about the ecology of *Polylepis* woodland birds and how this information can be used to improve their conservation status.

THE *POLYLEPIS* ECOSYSTEM

Polylepis (Rosacea) is a genus of about 28 – 30 species of shrubs or usually small (3-5 m) and gnarled trees, that sometimes can reach 15 – 22 m in height (Mendoza and Cano, 2011; Kessler and Schmidt-Lebuhn, 2006; Fjeldså and Kessler, 1996, Kessler *et al.*, 2014; Per. Obs.). Members of this genus are found from Venezuela to northern Chile and in a disjunct sub-tropical population in the Sierras de Cordoba, Argentina (Simpson, 1979; Kessler 2006) (Fig. 1). Although several plant species are restricted to the highest parts of the Tropical Andes (3,500 m to 4,700); some species can be present as low as 900 m (Renison *et al.*, 2013), or as high as 5,200 m (Troll, 1973; Simpson, 1979; Kessler, 2005a). In fact, together with *Juniperus tibetica* at 4,900 m, *Polylepis* spp. are recognized as the only trees that can survive at such high altitudes, and their forests/woodlands represent the tree line limit of the world (Purcell *et al.*, 2004; Kessler *et al.*, 2014).

Polylepis *distribution*

One of the defining characteristics of *Polylepis* woodlands is its fragmented and patchy distribution at the landscape/regional scale, which has been attributed to natural factors by some authors, and to human activities by others. By many, this fragmented distribution was attributed to the tree's dependence upon specific microclimatic conditions, where topographical features like slopes with cloud condensation (Troll, 1959), or boulder screes and rocky slopes, provided warmer, and moister lower-elevation-like conditions in high elevation habitats that are otherwise unsuitable for tree growth (Weberbaueri, 1943; Koepcke, 1961; Walter and Medina 1969; Simpson, 1986). However, Kessler *et al.*, (2014) found evidence that *Polylepis* is adapted to survive very low temperatures and that the soil temperatures where it is found are below the global mean for high-elevation treeline forest.

Moisture balance, fire, waterlogging, cloud cover (Gosling *et al.,* 2009) and air temperatures (Kessler *et al.,* 2014) have also been identified as critical factors in determining the niche space availability.

In addition, environmental changes during the last glaciation likely affected the distribution of *Polylepis* (Simpson, 1979; Gosling *et al.*, 2009). This has been supported by pollen records from Bolivia and Peru dating back 113,000 – 112,000 cal yr BP (Gosling *et al.,* 2008) where the records suggest that the range and size of *Polylepis* woodlands constricted dramatically as the climate warmed and dried (Gosling *et al.,* 2009), and a few areas remained as isolated refuges long enough to develop several endemic plant (Simpson, 1986; Rauh, 1988) and bird species (Fjeldså, 1992; 2002; Fjeldså *et al.,* 1999). Fewer studies implicate humans as the causative factor during those eras, though pollen records from Junin Lake and in the central Andes indicate a major decline of *Polylepis* forest ~ 10,000 yrs ago with human settlement (Hansen *et al.,* 1994) where fire was a very important factor in its distribution according to soil charcoal evidence (di Pasquale *et al.,* 2008); however, the origin of these fires (natural or human) remains ambiguous (Gosling *et al.,* 2009).

Human activities likely have contributed to the limited distribution of *Polylepis* forest. Ellenberg (1958) proposed that fire and cattle destroyed huge extents of *Polylepis* forest since human settlement, and that the current relict patches survived due to the inaccessibility of the fire and cattle to rocky slopes. Kessler (1995b) concluded that *Polylepis* is not restricted to favorable microclimates, and that *Polylepis* could survive in a variety of soil types with the exception of seasonally water-saturated or salty soils (Kessler, 1995b; Kessler, 2002). He recognized that fire and cattle could have played a very important role in the actual distribution of *Polylepis*, at least in Bolivia (Kessler, 1995a, b;

Kessler, 2002). Evidence that *Polylepis* trees are smaller in areas affected by human activities, compared with areas with fewer disturbances, also is provided by Renison *et al.*, (2005) and Kessler *et al.*, (2014).

Other studies have proposed that the current *Polylepis* distributions would be relatively close to the natural ones, and that the actual fragmented and patchy distribution would be the consequence of both natural and human forces (Sylvester *et al.*, 2014). Changes in environmental factors during the last glacial era in an irregular topography, exacerbated by human activities like fire, cattle and logging during the last centuries, would be the principal causes of the forests distribution (Chepstow-Lusty *et al.*, 1998; Cheptow-Losty *et al.*, 2005; Hanselman *et al.*, 2005; Gosling *et al.*, 2009; Kesser *et al.*, 2014; Sylvester *et al.*, 2014).

Centers of endemism

Although *Polylepis* forests present a fragmented and patchy distribution along the Andes, they tend to be geographically clustered, with the greatest concentrations of forest aggregated in what was denominated as the Center of Endemism (Fjelsa, 1992). Zutta et al (2012) and Zutta, (2009) concluded that ~60% of the total extension of *P. sericea* and ~70% of *P. weberbaueri* are located between Cordillera Blanca and Cordillera of Lima; while Cuzco and Ayacucho are considered as the diversification center of *Polylepis*; with 10 different *Polylepis* species (Mendoza and Cano, 2011). These areas are situated among mountain ranges with several glacial valleys ("quebradas") surrounded by enormous glaciated mountains that reach altitudes over the 5,700 m (Carey *et al.*, 2012). They also probably served as refuges during climatic cycles of the Pleistocene, providing ecological

stability over long periods that contributed to the development of several endemic species (Fjeldså *et al.*, 1999; Fjeldså, 2002).

Based on biogeographic patterns of birds associated with *Polylepis* woodlands, Fjeldså (1992) recognized three centers of endemism, two in Peru and one in Bolivia (Fig. 1 and Table 1). The first is located between Marañon Center and the West Peruvian Andes and West Peruvian Centers (Cordillera Blanca and Cordillera of Lima), where 7 bird species are of conservation concern, 12 are endemic, and 13 are associated with *Polylepis* forest (Table 1). The second is the Apurimac Center (Apurimac Canyon, Cordillera Vilcabamba and Cordillera Vilconota), where 6 species are of conservation concern, 13 are endemic and 8 are associated with *Polylepis* forest. Finally, the Cochabamba Center in Bolivia has 7 endemic species and 2 of them are associated with *Polylepis*. According to Fjeldså (1993), with the protection of these three areas, 55% of all the endemic birds and 67% of all the threatened birds of the High Andes would be conserved.

Plant communities of Polylepis *woodlands*

Although these forests are called *Polylepis* woodlands, they are not single-species forests and several plant species play important roles in the ecology of this ecosystem and its bird community (Tinoco *et al.*, 2013). Changes in dominance of *Polylepis* and a turnover of the plant community can be observed along an altitudinal distribution (Kessler, 2001; Kessler, 2005a). At lower (2,700 to 3,400 m) and more humid zones, these forests have been called *Polylepis* cloud forest (Fjeldså, 1992; Kessler, 2005a) and represent a minor component of the continuous cloud forest where several tree species like *Weinmannia, Alnus, Clethra, Escallonia, Vallea, Citharexylum, Clusia* and *Oreopanax* are present (Kessler, 2005a). Here, the bird community is mostly composed of cloud forest bird

species (e.g. Tanagers, Flowerpiercers) and lacks *Polylepis* specialist birds (Kessler, 2005a; Kessler *et al.*, 2001).

With increasing altitude (3,400 – 3,800 m), *Polylepis* starts to co-dominate the forest with several shrubs and trees of *Gynoxys, Buddleja, Baccharis, Senecio* and *Berberis*, all of which constitutes the mixed *Polylepis* forest (Fjeldså, 1992; Kessler, 2005a, Servat, 2006). Some of these patches can be the biggest homogeneous stands within the *Polylepis* forest (e.g., one single patch of ~150 ha in Cordillera Blanca), but often have borders that are generally blurred and difficult to distinguish from the matrix, especially at lower altitudes. These other species form a low-contrast matrix dominated by *Gynoxys* and other shrubs (Per Obs.). Many of these trees (not only *Polylepis*) are covered by a high quantity of epiphytes like bromeliads, mosses, lichens, and *Tristerix,* a mistletoe of the Loranthaceae family, all of which increase increase the ecological complexity of the mixed *Polylepis* forest and play an important role in the ecology and dynamics of several *Polylepis* birds (Servat, 2006; Tinoco *et al.,* 2013).

At higher (>3,800 m) and drier zones, *Polylepis* is the dominant species and occurs in isolated patches of evergreen woodland, surrounded by a distinctive vegetation matrix of small shrubs or grasslands far above of the continuous forest (Kessler, 1995; Fjeldså 2002). Commonly referred to as true *Polylepis* forest, these small (0.1 – 1 ha) to medium-sized (5 – 9 ha) patches with abrupt limits are composed of mature tall *Polylepis* trees up to 16 to 22 m in height (Kessler et al 2014, Per. Obs), but without a co-dominance of other arboreal/shrub species. The understory is usually covered by mosses and several small plants of *Sartuleja, Loasa, Chuquiraga, Senecio, Jungia, Perezia, Werneria, Valeriana, Minthostachys,* and *Nototriche,* which are considered medicinal plants by local people (Kolff and Kolff, 2005). Many grass species, like *Festuca, Calamagrostis, Stipa,*

Muhlenbergia, and *Agrostis* also tend colonize the borders and constitute the principal vegetation of the *puna* matrix (Kessler, 2005a). Here, other shrubs/trees (*Gynoxys, Buddleja, Lupinus*) form their own small patches (0.1 -1 ha) or stand used as "stepping stones" by several birds (e.g. *Xenodacnis parina, Lesbia victoriadae, Metallura phoebe*) including some *Polylepis* specialists (e.g. *Zaratornis stresemanii, Chalcostigma stanleyi, Oreomanes fraseri*) (Lloyd and Marsden, 2011; Tinoco *et al.*, 2013; Per. Obs.).

Bird communities of Polylepis *woodlands*

Polylepis forests are considered among the most threatened ecosystems of the tropical Andes (Fjeldså, 2002) and support several bird species that are of conservation concern (IUCN 2105, Stotz *et al.*, 1996). A total of 214 bird species are usually associated with *Polylepis* woodland and around 51 of them show a strong degree of association with *Polylepis* woodlands; 20 are of conservation concern and 14 are recognized as *Polylepis* specialized birds (Fjeldså, 2002). The Royal Cinclodes (*Cinclodes aricomae*) is one of the most threatened bird species worldwide and is listed as critically endangered with an estimated population of 250 individuals restricted to the *Polylepis* woodlands of southeast Peru (Cuzco, Apurimac, Ayacucho, and Junin) (BirdLife International 2016, Aucca *et al.*, 2015). The Ash-breasted Tit-tyrant (*Anairetes alpinus*) and the White-browed Tit-spinetail (*Leptasthenura xenothorax*) are listed as endangered species. Although the population size was not estimated for the former, it is thought to be made up of between 150 – 700 mature individuals, while 250 – 999 mature individuals was estimated for the latter species (BirdLife International, 2012). The main populations of the Ash-breasted Tit-tyrant are located in the three centers of endemism, while the White-browed Tit-spinetail is mainly restricted to the high *Polylepis* forest of Apurimac and Cordillera Vilcanota in Cuzco

(Schulenberg *et al.*, 2010) (Fig. 2). The Plain-tailed Warbling-finch (*Poospiza alticola*) is another bird listed as endangered and associated with mixed *Polylepis* woodlands mainly in Cordillera Blanca. Its population has not been estimated, but it is described as a rare species by Frimer and Møller (1989) and Servat, (2006). The White-Cheeked Cotinga (*Zaratornis stresemanni*) is listed as vulnerable, with a population size of 1,000-4,000 mature individuals restricted to *Polylepis/Gynoxys* forest of Cordillera Blanca, C. Occidental and Central (BirdLife International, 2012). The Tawny Tit-spinetail (*Leptasthenura yanacensis*) is a near threatened species and is described as uncommon in three disjunct populations of *Polylepis* woodlands of Cordillera Blanca, Apurimac/Cuzco area and Bolivia (Schulenberg et al, 2010) (Fig. 2).

Other birds of conservation concern are less restricted and with relatively large ranges. The Giant Conebill (*Oreomanes fraseri*) is the most characteristic bird of *Polylepis* woodland (Vuilleumier, 1984; Fjeldså, 2002), distributed from southern Colombia to southwestern Bolivia and, with recent records from the north of Chile (Howell and Webb, 1995) and Salta, Argentina (Mazar-Barnett *et al.*, 1998). This species is listed as near threatened and is recognized as a very specialized and restricted *Polylepis* bird (Servat, 2006). Species like the Tit-like Dacnis (*Xenodacnis parina,)*, Thick-billed Siskin *(Spinus crassirostris),* Stripe-headed Antpitta *(Grallaria andicolus),* Black Metaltail (*Metallura phoebe*), Ancash Tapaculo (*Scytalopus affinis*), D'Orbigny's Chat-tyrant (*Ochtoeca oenhantoides*), are not listed as threatened species, though their populations are declining and warrant careful monitoring.

Some of the threatened bird species tend to be locally common (e.g *Leptasthenura xenothorax, Poospiza alticola, Zaratornis stresemanni*), despite declining populations due to habitat loss and fragmentation (Fjeldså, 2002; Servat, 2006; Tinoco *et al.*, 2013). Lloyd

(2008c) concluded that the species most threatened have very low population densities, with less than 5 individuals per km^2 estimated for the most endangered species (e.g. *Cinclodes aricomae, Anairetes alpinus*) and around 25 for the a most common, but still endangered species (e.g. L. *xenothorax*). These species were mainly found in large *Polylepis* patches (>12 ha), which usually maintain the highest bird densities (Lloyd, 2008a). Nevertheless, small *Polylepis* patches and small shrub/tree patches of other species, especially *Gynoxys* (Tinoco *et al.*, 2013), have also showed an important role in maintaining connectivity and facilitating the movements of birds among patches (Lloyd and Marsden, 2011).

Previous studies of the *Polylepis* bird community suggest that the matrix and the degree of disturbance exert a strong influence on its composition. Bellis *et al.*, (2009) and Sevillano-Ríos *et al.*, (2011) confirm the observations of Lloyd (2008a, c) that a large percentage of the species reported inside the forests were species of the surrounding vegetation types. Sevillano (2010) suggests that the bird communities in many areas exhibit a pattern consistent with the Intermediate Disturbance Hypothesis (IDH) (Connell, 1978), with high species richness present in patches with moderate degrees of disturbance due to the presence of both *Polylepis* specialists and matrix-associated birds; while very conserved or perturbed forest are mainly occupied only by *Polylepis* specialists or by matrix bird species respectively (Hjarsen, 1999; Matthysen *et al.*, 2008; Sevillano-Ríos, 2010). However, these patterns could also be influenced by altitude, which could affect the bird community directly, but could also be correlated with human disturbance, making it difficult to separate the effects. At lower altitudes many non-*Polylepis* birds tend to occupy the forest but a higher degree of disturbance is more likely; while at higher altitudes, where only *Polylepis* specialists are more adapted to survive, a lower degree of human disturbance

is apparent. However, these hypotheses have not been tested yet (Cahill and Matthysen, 2007).

Changes in the vegetation structure along the altitudinal gradient also affect the bird community structure in other ecosystems (Jankowski *et al.,* 2013), but not many studies have evaluated these possibilities for *Polylepis* forests. Kessler *et al.,* (2001) evaluated the patterns of species richness and endemism for birds along an elevation gradient from cloud forest to mixed *Polylepis* forest (1,600 – 3,600 m) and observed a hump-shaped pattern for species richness, while the patterns of endemism showed a constant increase with altitude. These patterns were unrelated to the vegetation patterns, and the authors suggest that other ecological requirements like moisture and habitat complexity are more important than altitude. However, a high correlation between lower altitudes (3,800-4,200 m) and the abundance of 7 *Polylepis* bird species was found by Lloyd (2008a), while just one species was correlated with higher elevations. In contrast, he also found that mature *Polylepis* forests with tall, dense vegetation cover, high density of large trees and primary forest ground cover were very important factors to maintaining higher abundances of several *Polylepis* bird species (Lloyd 2008a). These observations suggest that *Polylepis* forest structure is important to conserve several *Polylepis* specialist birds, however how the influence of these factors varies along altitude is not totally clear. Understanding the interactions of other ecological factors with altitude in driving the bird community could help to improve current conservation efforts.

CONSERVATION

Protecting and restoring *Polylepis* woodlands is essential for the conservation of their constituent species. These efforts must consider the recent ecological findings of

several researchers to improve the management of *Polylepis* habitat for its bird community. During the last decade some efforts conducted mainly by Asociación de Ecosistemas Andinos (ECOAN), in cooperation with American Bird Conservancy (ABC), Conservation International, The Mountain Institute, and other local NGOs, have started to develop new strategies for *Polylepis* conservation and recovery in Peru. These include agreements with local people in order to reduce burning and grazing of the *Puna* matrix, and reduce logging from the forests, along with carrying out planting campaigns in return for indirect benefits to increase their quality of life (e.g., Aucca and Ramsay, 2005). In particular, the purchase or allotment of lands for conservation purposes is a strategy that has positive outcomes. Abra Malaga, in Cuzco, where recent ecological studies have been developed (e.g. Kessler, 2014; Sylvester *et al.*, 2014), was the first private conservation area created with the primary purpose of conserving a *Polylepis* bird community. Similar efforts are now underway in Cordillera Huayhuash and Conchucos in Ancash and have created new areas of conservation like Communal Reserves. However, the actual amount of *Polylepis* forest under official protection is poorly representative. In Peru, only about 9-12% is protected by the government (Zutta *et al.*, 2012), and that only occurs in Cordillera Blanca, through Huascaran National Park, while the zones of Cordillera of Lima and Apurimac/Cuzco are not officially protected.

FUTURE INVESTIGATION AND PROJECTS

Elsewhere, studies on genetics and different population parameters such us population trends, abundance, movement and dispersal and habitat requirements have been used to recover several endangered species and improve their management (Caldwell *et al.*, 2013; Rivera-Milán *et al.*, 2015; Sillett *et al.*, 2012). However, much of this information is

almost nonexistent for the majority of the Neotropical birds, creating challenges for the conservation of many threatened Neotropical bird species.

Although several studies have been developed during the last 10 years related to the ecology and conservation of *Polylepis* woodlands and their contituent bird species (e.g. Lloyd, 2008a, b, c; Lloyd and Marsden, 2008; Tinoco et al., 2014), no genetic study has been developed for *Polylepis* birds. Many of these species are distributed in meta-populations along the Andes, with apparently little or no genetic flow, compromising their population viability. Genetic studies on target species (e.g Royal Cinclodes, Ash-breasted Tit-tyrant) in addition to quantitative studies of their populations could be crucial to help guide our current conservation efforts. Previous studies have shown the relationship between extinction probability or vulnerability and elevation (Sekercioglu *et al.*, 2008), and further studies should examine these relationships for *Polylepis* birds because it is very likely that even more species will be threatened due to future climate change for example (Sekercioglu *et al.*, 2012).

Finally, in order to validate the effectiveness of different conservation tools, we have to employ an adaptive management framework with continued monitoring of our target species. Successful efforts need to be published and widely distributed and adapted and applied by NGOs, government agencies, universities, and through community-based efforts along the entire *Polylepis* range.

CONCLUSION

In conclusion, future projects focused on conservation of *Polylepis* forests and their associated bird communities should incorporate the fallowing guidelines:

- Consider patterns of endemism and populations of vulnerable species at regional scales (Fjeldså, 1993). Several endangered endemics and range-restricted bird species inhabit *Polylepis* woodlands and have very low populations (Lloyd, 2008a). The current amount of protected *Polylepis* woodlands likely is not sufficient to support viable populations of vulnerable species, and protecting greater amounts of land should be a priority along the Andes (Zutta *et al.*, 2009; Sevillano *et al.*, 2011).

- Protect and manage remnant *Polylepis* forests and especially large patches (~>10 ha), which will serve as the cornerstone of conserving the *Polylepis* bird community (Lloyd, 2008b). Mature *Polylepis* forests, with tall stems, dense canopy, and ground cover dominated by mosses, are important for several specialist *Polylepis* birds (Lloyd, 2008b) and must be protected and managed, regardless of their patch sizes (Cahill *et al.*, 2007; Tinoco *et al.*, 2013).

- Restore and conserve small *Polylepis* patches, as they may play the role of "stepping stones" and/or "drift fences' facilitating movements of *Polylepis* bird species and increasing connectivity among bigger patches (Lloyd and Marsden, 2009). Clusters of *Gynoxys and Budleja* shrubs may play the same role and should also be considered in future conservation projects and research (Tinoco *et al.*, 2013).

- Reduce fire, cattle grazing, and logging in order to favor natural forest regeneration (Koenen, 2000; Renison *et al.*, 2002; Renison *et al.*, 2005; Cierjacks *et al.*, 2008; Renison *et al.*, 2010). The inclusion of local human communities in these efforts is necessary to achieve long-term conservation objectives (e.g. ECOAN; Compañía Minera Antamina Asociación Ancash 2004; Cahill *et al.*, 2007).

- Investigate how composition of the matrix influences patch dynamics and habitat quality (Lloyd and Marsden, 2008). Studies should also examine elevation and seasonality due their relevance to understanding the effects of climate change (Sekercioglu *et al.*, 2012).

- Use an adaptive management framework that includes monitoring of target species to facilitate the development of more applied projects with better outcomes.

The integration of all of this knowledge is expected to produce more effective ways to conserve the whole *Polylepis* bird community.

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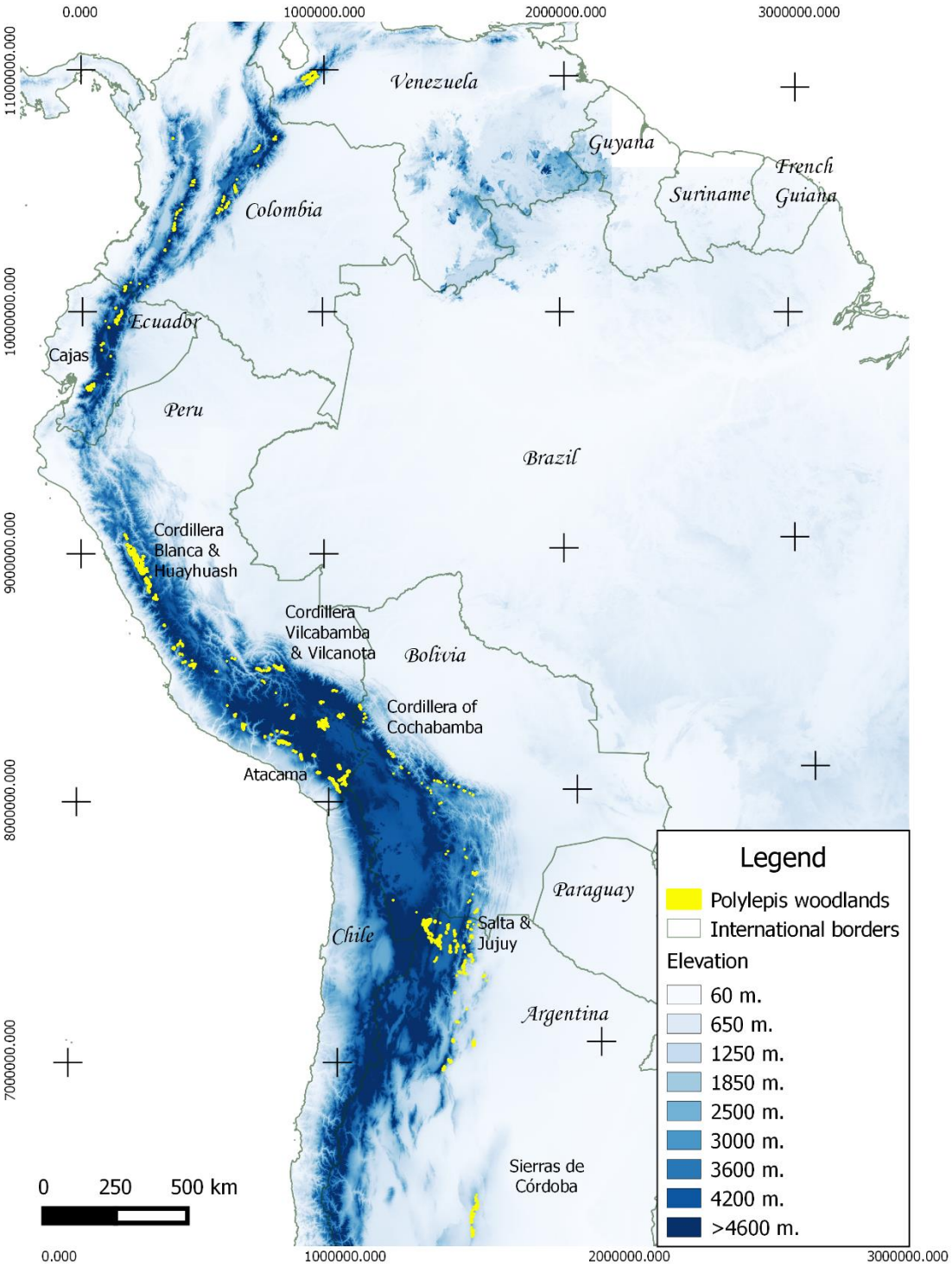
FIGURES

Fig. 1. *Polylepis* forest distribution along South America. Main localities are indicated within each country. Cordillera Blanca and Cordillera Huayhuash in Central Peru, harbor the highest extensions of *Polylepis* forest throughout the whole distribution.



Map based on Arnal, H., A. Sampson, G. Navarro, W. Palomino, W. Ferreira, K. Romoleroux, D. Caro, I. Teich, E. Cuyckens, C. Antezana, S. Arrazola, C. Aucca, J. Balderrama, S. Beck, S. Burneo, N. De la Barra, A. Bustamante, Y. Fandinso, G. Ferro, I. Gomez, G. Guzman, J. Iglesias, J. Irazabal, P. Lozano, M. Mercado, A. Monsalve, D. Renison, S. Salgado y E. Samochuallpa. 2014. Mapa Pan Andino de Bosques de prioritarios para Conservación. American Bird Conservancy, The Plains, USA. Map Elavoration: Steven Sevillano.

Fig. 2. Distribution of six *Polylepis* specialist birds along the Andes. Some of these species are restricted to the centers of endemism proposed by Fjelsa in 1992. Bird images from http://www.hbw.com/; Maps from BirdLife International and NatureServe (2014).

Table 1. Endemic species located in the three centers of endemism proposed by Fjeldså (1992).

Center of Endemism	**Endemic and threatened species**
Cordillera Blanca and Cordillera of Lima (Northern Peru)	*Endemic:* *Scytalophus affinis*, Mecocerculus leucophrys pallidior*, Atlapetes rufigenis**(NT), Poospiza alticola**(EN), Asthenes aff. dorbignyi unnamed sub new sp.(DD) Upucerthia serrana*, Zaratornis stresemanii*(VU), Xenodacnis parina petersi*, Poospiza rubecula (EN), Metallura phoebe*, Letasthenura pileata*, Cranioleuca antisiensis baroni*,* *Not Endemic:* *Anairetes alpinus** (EN), Oreomanes fraseri** (NT), Leptasthenura yanacensis** (NT),*
Apurimac Center: Apurimac Canyon, Cordillera Vilcabamba and Cordillera Vilcanota (Southern Peru)	*Endemic:* *Aglaeactis castelnaudii*, Oreonympha nobilis, Asthenes ottonis, A. virgata, Cranioleuca albicapilla*, Xenodacnis parina parina*, Atlapetes forbesi*, Atlapetes terborghi (NT), Atlapetes canigenis, Poospiza caesar, Scytalophus urubambae, Cinclodes aricomae**(CR), Leptasthenura xenothorax** (CR).* *Not Endemic:* *A. urubambensis (NT), Anairetes alpinus** (EN), Oreomanes fraseri** (NT),*
Cochabamba Center: (Bolivia)	*Endemic:* *Oreotrochilus adela, Asthenes heterura, Diglossa carbonaria, Saltator rufiventris*, Atlapetes fulviceps, Poospiza boliviana, P. garleppi*.*

* weaker association with *Polylepis* ; ** high association with *Polylepis*

CHAPTER III

SEASONAL PATTERNS OF AVIAN DIVERSITY ALONG AN ANDEAN ELEVATION GRADIENT

ABSTRACT

The tropical Andes are recognized as one of the most diverse places in the world. Yet, our understanding of the extent to which elevation and seasonality drive diversity in the High Andes (>3,500 m) remains incomplete, despite that climate change is expected to both alter and threaten montane ecosystems. In this study, I described seasonal patterns of avian species richness in *Polylepis* forests distributed along an elevational gradient (~3,300 – 4,700 m) in five glacial valleys in Huascaran National Park, within the Cordillera Blanca range of Peru. In 2014-2015, birds were surveyed at 130 point count locations and systematically observed between points during wet and dry seasons. Number of species expected (S(est)) was calculated using the asymptotic Abundance-Coverage Estimator (ACE) for valleys, seasons, and within 100-m elevational bands. An estimated 70 to 100 species occupied each of the five glacial valleys, with 10 bird species dominating over half of the individuals recorded in communities. Species richness was lower in dry than wet seasons, particularly at lower elevations (<3,800 m). Reductions in species richness during the dry season were least likely to occur at high elevations in areas with *Polylepis* forest remnants. Species richness peaked at mid-elevations for the bird community overall and for three guilds (nectarivores, granivores and aerial insectivores), and was highest at ~4,000 m. Number of frugivorous species decreased with elevation, whereas terrestrial insectivores increased. The greatest number of endemics and threatened species, which primarily were *Polylepis* specialists, were found at ~4,300 m. The high estimates of species richness,

which exceeded those of previous studies, challenge the idea that high elevation habitats are not as speciose as lower elevations and, rather, are species rich and home to many endemic and threatened species. Although declines in species richness during dry seasons suggest that the projected warmer and drier conditions may negatively affect certain species in the region, my work provides evidence that *Polylepis* forest fragments might provide important refuge or buffering against future changes in climate.

RESUMEN

Los Andes tropicales son reconocidos como uno de los lugares más diversos del mundo. Sin embargo, nuestra comprensión de como la elevación y estacionalidad determina diversidad en los Altos Andes (> 3,500 m) sigue siendo incompleta. Desafortunadamente, se espera que el cambio climático también altere tanto los patrones altitudinales como estacionales, amenazando a los ecosistemas de montaña. Este estudio describe los patrones estacionales de riqueza de especies de las aves asociadas a los bosques de *Polylepis* distribuidos a lo largo de un gradiente altitudinal (~ 3,300 – 4,700 m) en cinco valles glaciares de la Cordillera Blanca - Parque Nacional Huascarán, Perú. Durante el 2014-2015, las aves fueron censadas en 130 puntos y reforzadas mediante observaciones sistemáticas entre puntos durante las estaciones de lluvias y estiaje. Estas observaciones, por separado y en conjunto, se utilizaron para calcular el número de especies esperadas S(*est*) para cada valle glacial durante cada temporada a través del estimador asintótico de Cobertura de Abundancia (ACE) en bandas altitudinales de cada 100 m. Se estima que entre 70 y 100 especies de aves ocuparon cada uno de los cinco valles, con sólo 10 especies que dominaban más de la mitad de los individuos registrados en la comunidad. La riqueza de especies fue ligeramente menor durante la época seca, especialmente en elevaciones más bajas (<3,800 m). La riqueza de especies alcanzó un máximo a elevaciones intermedias y fue más alta a ~ 4,000 m durante ambas estaciones. El número de especies frugívoras disminuyó con la elevación, mientras que los insectívoros terrestres aumentaron. La riqueza de los tres gremios - nectarívoros, granívoros e insectívoros aéreos - alcanzó un máximo a elevaciones intermedias. El mayor número de especies endémicas y amenazadas - principalmente especialistas de *Polylepis* - se

encontraron alrededor de ~ 4,300 m sin cambios entre estaciones. Las altas estimaciones de riqueza de especies, que superaron estudios previos, desafían la idea de que los hábitats de gran altitud no son tan ricas como las de elevaciones más bajas y, más bien, no solo son ricas en especies, sino el hábitat de muchas especies endémicas y amenazadas. Aunque la disminución de la riqueza de especies durante las estaciones secas sugiere que las condiciones más cálidas y secas proyectadas en la región pueden afectar negativamente a algunas especies, mi trabajo proporciona evidencia de que los fragmentos de bosque de *Polylepis* podrían proporcionar de refugio y/o ser un importante amortiguador contra los futuros cambios climáticos.

INTRODUCTION

The tropical Andes are recognized as one of the most diverse places in the world (Myers *et al.,* 2000). Their impressive diversity is often attributed, in part, to complex topography and elevational gradients that give rise to high beta diversity (Jankowski *et al.,* 2013) and high endemism (Young, 2007; Young *et al.*, 2009). Most studies of elevational changes in diversity have focused on low to mid-elevation patterns (Terborg, 1977; Patterson *et al.,* 1998; Kessler *et al.,* 2001; McCain, 2004; 2005; Herzog *et al.*, 2005;), and few studies have described how species diversity changes with elevation in the High Andes (>3,500 m).

Studies of montane birds show complex patterns of species richness with elevation. A global meta-analysis recognized four main patterns of diversity along elevational gradients: decline with elevation, low elevation plateau, low plateau with a mid-elevation peak, and mid-elevation peak (Fig. 3) (McCain, 2009; McCain and Grytnes, 2010). Climatic variables and proxy measures of productivity, particularly temperature and water availability, were the main global drivers of bird diversity along elevation (McCain, 2009). For example, on wet mountains, bird diversity declined with elevation or showed a low-elevation plateau, whereas dry mountains tended to show mid-elevation peaks (McCain, 2009; McCain and Grytnes, 2010). In one of the first elevational studies in Peru (500 – 3,500 m), the number of bird species inhabiting the forest decreased with elevation, though specific patterns varied among foraging guilds (Terborg, 1977). Patterson *et al.*, (1998) reported a similar pattern of decline for birds and bats, but not rodents, along a 300-3,500m gradient in Manu National Park, Peru. Later studies in Bolivia found mid-elevation peaks of species richness at 1,000 m to 2500 m elevation with a surprisingly consistent high elevation plateau at ~3,500 m in some areas (Herzog *et al.*, 2005; Kessler *et al.,* 2001).

Another important question is how seasonality may contribute to patterns of diversity in the Andes. Seasonality is known to play an important, though sometimes under-recognized, role in maintaining and promoting diversity in a variety of systems (Shimadzu *et al.,* 2013). Seasonality shapes a wide variety of ecological processes and patterns including migration (Somveille *et al.,* 2015; Faaborg *et al.,* 2010), species distributions (Brockman and van Schaik, 2005), reproductive cycles (Winemiller, 1993; 1998), and ecosystem productivity (Croll *et al.,* 2005; Potter *et al.,* 1993). Whereas temperate zones generally show pronounced seasonality in temperature and precipitation (Faaborg *et al.,* 2010), the tropics tend to have a high thermal stability with distinct dry and wet seasons (Marengo *et al.,* 2009), which has been interpreted as support for the hypothesis that thermic seasonal stability promotes species diversity (Karr, 1976). Despite the thermal stability, species in the tropics do respond to seasonal differences in rainfall, though responses vary widely (Loiselle and Blake, 1991; Winemiller, 1993; Winemiller, 1998; Herzog *et al.,* 2003). For birds, especially juveniles, access to resources during the wet season is critical for surviving the more stressful dry season (Levey, 1988; Loiselle and Blake, 1991; Stiles, 2008).

Although montane communities are vulnerable to a wide variety of stressors, climate change is one that is expected to alter both elevational and seasonal patterns in ways that could profoundly affect species distributions, migratory behavior, and species interactions, all with the potential to threaten entire ecological communities (Herzog *et al.,* 2011; Wormworth, 2011; Sekercioglu *et al.,* 2008). The magnitude of climate change in the tropical Andes is well-illustrated by studies of mountain glaciers in the Cordillera Blanca (Vuille *et al.,* 2008; Silverio *et al.,* 2005; Georges *et al.,* 2004; Mark *et al.,* 2010). For example, a warming trend of 0.39°C per decade was recorded between 1951 and 1999

(Mark and Seltzer, 2005), and glacial areas have experienced >30% loss during the last century (Vuille et al, 2008). Recent studies show that streamflow during dry seasons has declined since 1983 with further declines expected (Mark *et al.,* 2010), affecting ecological communities, as was observed elsewhere (Pearce-Higgins and Green, 2014; Visser *et al.*, 2004; Coppack and Pulido, 2004). However, unlike glaciers or streamflows that have been continuously monitored for years, systematic data are not available to assess changes in *Polylepis* biodiversity over time.

An already threatened ecosystem that might be further compromised by changes in climate and seasonality is the *Polylepis* forest, which represents one of the highest elevation forests in the world (Purcell *et al.,* 2004; Hoch and Korner, 2005). Even though high elevations (>3,500 m) are purported to be relatively species poor (Gaston, 2000), *Polylepis* forests are hotspots of avian endemism and diversity (Fjeldså and Kessler.,1996; Fjeldså, 2002; Fjeldså *et al.,* 1999; Lloyd, 2008; Lloyd and Marsden, 2008). The high diversity is particularly impressive, given the harsh and seasonally variable environment. During the dry season, birds living in the *Polylepis* forest are exposed to highly stressful conditions that include more extreme temperatures and lower food availability than in wet seasons (Herzog *et al.,* 2005; Herzog *et al.,* 2003). Because co-existence and persistence of many species are thought to result, in part, from behavioral and physiological adaptations to a harsh environment (Wolf and Hainsworth, 1972; Jankowski *et al.,* 2013; Projecto-Garcia *et al.,* 2013; DuBay and Witt, 2014), any changes could prove devastating. Thus, *Polylepis* bird communities may be especially sensitive to changes in seasonality associated with the projected expectations of: 1) warming temperatures, especially at higher elevations due to the combined influence of greenhouse gases and solar radiation (Urrutia and Vuille, 2009; Seiler *et al.,* 2013) and 2) dryer conditions associated with reduced streamflow and water

availability (Vuille *et al.*, 2008; Urrutia and Vuille, 2009). Changing climatic conditions also could increase the probability of massive extinctions of uniquely adapted communities on high mountains due to dispersal constrains during stressful conditions (Lawler *et al.*, 2009), especially for those endemic and very specialized species.

Within this context, understanding seasonal patterns of diversity at high elevations (>3,500 m) can provide insight into how bird communities may be impacted by more extended and more frequent dry conditions in the future. As such, this study describes seasonal patterns of species richness in *Polylepis* forests distributed along an elevational gradient (~3,300 – 4,700 m) in Cordillera Blanca of Peru.

METHODS

Cordillera Blanca, located in the Ancash Department in Peru (-9.34, -77.39), is the highest tropical mountain range in the world stretching 130 km from north to south but only spanning 30 km longitudinally (Georges, 2004). Study sites were located within Huascaran National Park (HNP) and Huascaran Biosphere Reserve (HBR), both protected since 1975 and declared a world heritage site by UNESCO in 1985 (PNH Plan Maestro, 1990, 2002, 2010) (Fig. 4). The complex topography of the study area includes 61 deep glacial valleys spanning impressive elevational gradients that, in only a few kilometers, ascend from 2,400 m to over 5,000 m – reaching a staggering 6,768 m on Huascaran, the world's highest tropical mountain (Ames *et al.*, 1989; Byers, 2000). Each valley includes several patches of *Polylepis* forest surrounded by a matrix of shrubs, grasslands, wetlands, lagoons and other plant communities. These forests represent the largest extents of *Polylepis* woodland under protection in the world (Zutta, 2009; Zutta *et al.*, 2012). Mean annual rainfall is ~844 mm, with pronounced seasonality that includes dry (May to August)

and wet (September through April) seasons. Precipitation peaks from January through March (~130 mm per month), and is most abundant at higher elevations (Schauwecker *et al.*, 2014). Mean annual temperature is 17 °C and monthly averages are far less variable than daily temperatures that can plummet to -15°C at night and soar to 23 °C at noon during the dry season (Fig. 5).

Five of the glacial valleys on the Pacific slope were selected for this study based on accessibility, elevational gradients, and spatial distribution along the Cordillera Blanca. Three parallel valleys ranging from 3,300 to 4,700 m, were selected in the north of Cordillera Blanca (Parón, Llanganuco and Ulta), and two valleys (Llaca and Rajucolta) were located more centrally within the Cordillera and covered an elevational gradient from 3,800 to 4,700 m (Fig. 4). Data were collected during mid-May to mid-August 2014 and mid-January to mid-April 2015, corresponding to the dry and wet seasons, respectively (Fig. 5).

Bird surveys

I used a robust sampling design for multiple species to survey the bird community at 130 points (William *et al.*, 1997; Jolly, 1965; Kendall, 2001). Each point was visited over a period of three consecutive days and surveyed three times during the dry season by a single observer and five times during the wet season by two observers. At each point, the observer recorded all birds seen or heard within 50 m over a 10 min period. Surveys were conducted from sunrise (~0500-0600 h) to ~1200 h, and the order of surveys was reversed each visit to avoid bias related to bird activity, time of day, and/or observer experience (Lloyd, 2008). For each bird detection, time, species, number of individuals, linear distance from the point

count center, and habitat type were recorded. Individuals detected multiple times in a single visit were only counted once.

Points were separated by >150 m and stratified by elevation so as to span the entire elevational gradient of each valley (3,300 to 4,700 m). GPS coordinates and elevation (±10 m) were recorded and verified at each point. There were 30 points each in the larger valleys of Parón, Llanganuco and Ulta, and 20 points each in the smaller Llaca and Rajucolta valleys. A total of 70 points were located inside woodlands dominated by *Polylepis* trees, 46 in areas dominated by shrubs and short-statured trees, such as *Gynoxys/Buddleja*, 6 within *Eucalyptus* forest, and 8 in Puna grassland.

Because many *Polylepis* bird species are rare or difficult to detect in point counts (Lloyd, 2008; Herzog *et al.*, 2003), bird observations were recorded systematically as the observer walked between point counts during the same 3-day survey period. All birds detected were recorded, making note of species, number of individuals, habitat and their social context, that is if they were in co-specific group/mixed flock or in a pair. Point count elevation data, GPS tracks and Google Earth elevational models were used to estimate the elevation of each observation.

Birds were assigned to one of eight foraging guilds: aerial insectivores (species that primarily consume insects or other arthropods in the air or on leaves, branches or trunks of trees or shrubs); terrestrial insectivores (species that primarily consume insects on or near the ground); nectarivores (species that primarily consume nectar); granivores (species that primarily consume seeds); frugivores (species that primarily consume fruits or flowers); carnivores (species that primarily consume prey) and aquatics (species that primarily consume prey from water systems like rivers, lagoons or wetlands). The assignments were based on previous studies (Herzog *et al.*, 2003; Lloyd and Marsden, 2008), literature

review (Fjeldså and Krabbe, 1990) (APPENDIX A) and direct observations. Species recognized as endemic to Peru (Birdlife Conservation, 2015), highly specialized to *Polylepis* forests and/or listed on the International IUCN Red List of Threatened Species (2015) are considered as species of concern in this study.

Data Analysis

Species richness

It was estimated for each glacial valley in each season using the asymptotic abundance-coverage estimator ACE (Chao and Lee, 1992; Chao et al., 2000) based on individual abundance data (Colwell et al., 2012) and implemented with EstimateS v 9.1.0 (Colwell, 2013). This estimator is recommended for communities where several species are rare (Colwell et al., 2012) and is recognized as one of the most accurate (Reese et al., 2016). However, this estimator does not provide statistical variance estimation so a rarefaction analysis was also performed using 100 randomizations to create the interpolation and extrapolation curves (Colwell et al., 2012). The rarefaction was extrapolated up to 3,500 individual for Llanganuco and Ulta, and up to 2,500 individuals for Parón, Rajucolta and Llaca. Species richness also was estimated within 100 m elevation bands along the entire gradient during each wet and dry season.

Both for glacial valleys and for elevational bands, species richness was estimated using two different sets of data – one including only point count data, and one including point count and systematic data – given that point count data alone often underestimate species richness (Herzog *et al.*, 2003; McCain and Knight, 2013). I used the mean of the number of species observed per point count within each elevation band as a measure of apparent species richness and ACE S(*est*) as the expected species richness along elevation

between seasons. Differences between ACE estimations were assessed through a two-sample paired Wilcoxon test.

Relative abundance

In addition to species richness, I also estimated relative abundance of each species. To do this, I used mean encounter rate (# individuals/10 min) within each elevational band (Lloyd 2008). I also measured changes in species composition between seasons at the point count level by calculating the proportion of species detected during both seasons at each point count (overlap), and the proportion of species detected only in one of the two seasons.

A cluster analysis of similarity among study sites and along elevational bands was performed for each season. This was based on records of detected/non-detected species and hierarchical pair-group (UPGMA) algorithms using a Euclidean similarity index constrained by elevational bands and a bootstrap of 1,000.

RESULTS

Across the two seasons, 18,190 records of a total of 109 bird species were recorded using point count and systematic observations. During the dry season there were 6,049 records of 96 species, compared to 12,141 of 105 species during the wet season. Only 4% of records were not identified at species level, leaving 17,414 to be used in subsequent analyses. Point count data alone accounted for 51.1% of records (APPENDIX A), with systematic observations between point counts comprising the remainder. Along both seasons, 24.7% of the species (27 of 109) were always detected across the five glacial valleys. During the dry season, 33% of the species (32 of 96) were detected across them, while 38% of the species (40 of 105) were detected during the wet season.

Combining both seasons, 66 to 89 species were observed S(*obs*) in each of the five different valleys (Table 3), with more species detected in the three northern valleys (Paron, Llanganuco, and Ulta), than the southern valleys (Llaca and Rajucolta). The valleys of Llanganuco and Ulta were the most similar during each season, sharing 71% of their species (54 spp.) during the dry season and 66% (63 spp.) during the wet season. This similarity was also evident in the UPGM cluster analysis (Fig. 6). Numbers of species observed were not only higher than those previously reported for the Cordillera Blanca, but also for *Polylepis* forests in other High Andean landscapes (Table 2). An intensive temporal and spatial survey effort over two seasons was generally necessary to record the full suite of species in a valley, but in some valleys the species richness was comparably high in both seasons (e.g., Ulta, Llanganuco) (Table 3). The asymptotic estimator ACE, estimated that northern valleys hosted 92-97 species compared to 72-81 species in southern valleys (Fig.7).

The pattern of relative abundance within the avian community was characterized by strong dominance of a few species, with several rare species (Fig. 8). Over both seasons, 10 *Polylepis* bird species were recorded at high frequencies within each valley, accounting for 52% of all individuals observed (Fig. 9). The remaining 48% of bird records were from 99 other species. Two of the four most common species were endemics – the Baron's Spinetail (*Cranioleuca baroni*) and the Ancash Tapaculo (*Scytalophus affinis*). Another six species of concern were comparatively uncommon, including the Rufous-eared Brush-finch (*Atlapetes rufigenis*; percent of total records: 2.7%); the White-cheeked Cotinga (*Zaratornis stresemanii*; 1.3%); the Giant Conebill (*Oreomanes fraseri*; 1.6%); the Plain-tailed Warbling-finch (*Poospiza alticola*; 1.2%), the Tawny Tit-spinetail (*Leptasthenura yanacensis*; 1.1%) and the Ash-breasted Tit tyrant (*Anairetes alpinus*; 0.47%).

Overall, slightly fewer species were observed during the dry season than the wet season across all valleys (Wet: 107 vs dry: 94). There was a marginally significant difference with four of the five valleys diminishing in number by approximately 15 bird species between the wet and dry season (Mean difference= 12.91; t=-6.16; p=0.06) (Table 3). Species richness in the valleys of Llanganuco and Rajucolta showed the greatest declines as they transitioned from wet to dry (17 species) whereas Ulta was more stable over the two seasons (Fig. 10). Changes in species composition between the seasons were most pronounced at lower elevations (Fig. 11 a). On average, ~16% of the species were only detected during the dry season, ~50% of the species were only detected during the wet season, and ~ 31% of the species were detected during both seasons at each point count (Fig. 11b).

Using point count data alone, the pattern of species richness along the elevational gradient (mean and total observed) showed a bimodal pattern (Fig. 12), due to a gap in observations between 3,800 and 3,900 m because of the presence of large lagoons, Chinancocha and Orconcocha, and a big flat area that prevented locating point counts in those bands. No statistical differences were detected when only point count observations were used (W: 58 p=0.72; Mean diff. 0.8; t=-1.054 p=0.37), likely because species richness was underestimated with this method due to sparse detections.

However, species richness along each elevation band differed significantly between seasons when all observations were considered (S(*obs*): W:111 p=0.003; Mean diff. 9.6; t=-4.278 p=0.001 and ACE S(*est*): W:100 p=0.003; Mean diff. 12.36; t=-3.83 p=0.001) (Fig. 13). Moreover, using the ACE estimations and including systematic observations, a peak in species richness (observed and estimated) was evident at ~4,000 m during both seasons (Fig. 14 a-b). The two models that best fit the mid-peak pattern were quadratic with a

coefficient of R^2 =0.61 (p=0.003) and R^2 =0.77(p=0.0001) for the wet and dry season respectively (Table 4 & Fig. 14 b). Lower elevations (< 3,800 m) experienced the greatest decline in species during the dry season, decreasing from approximately 50 to 30 species.

When analyzing foraging guilds, the species richness of nectarivores and frugivores observed during point counts decreased with elevation, while granivores and aerial insectivores remained constant and only terrestrial insectivores increased (Fig. 15 a-e). These patterns persisted only for frugivores and terrestrial insectivores when systematic observations were added and re-scaled to the proportion of the total number of species (on that particular guild). For the other thee guilds (aerial insectivores, nectarivores, and granivores), species richness peaked at mid-elevations (Fig. 16 a-e).

The aerial insectivore guild was most frequently recorded along the entire elevational gradient, representing ~30-40% of the community (35 species) (Fig. 16 c). The highest proportion of aerial insectivores was found between 3,600 m and 4,300 m during the wet season (~70%), whereas at lower elevations they represented ~20% of the community during the dry season. Terrestrial insectivores were the second most frequently recorded guild, representing 30% of the community (19 species). The highest proportion of terrestrial insectivores (90%) was recorded at 4,000 m during the wet season, decreasing by ~10% during the dry season (Fig. 16 e).

Several other guilds were important constituents of the bird community. Nectarivores represented 10-15% of the community (11 species), and although no new species were added or lost along the entire elevation gradient during both seasons, range shifts and/or spatial rearrangements may be occurring between seasons because the guild declined by approximately 20% within each elevational band during the dry season (Fig.16 b). The only elevation and time at which all species of nectarivores were observed was at 4,000 m

during the wet season. Frugivores (13 species) usually represented less than 10% of the whole community, except at lower elevations where they represented around ~25% of the species present (Fig.16 d). Only one frugivore (*Zaratornis stresemanii*) occupied elevations > 4,000 m and its distribution was much more restricted to even higher elevation (> 4,300 m) during dry than wet seasons (unpublished data). Granivores represented ~15% of the community (14 species) and were the only guild most common at mid-elevations (4,000 to 4,300 m) during the dry season (W: 93, P=0.01; Mean diff. =0.19; t=3.3; p=0.006) (Fig.16 a). Finally, the two other guilds – carnivores (7 species) and aquatic birds (10 species) – were most common in the wet season, though not specifically associated with *Polylepis* forest.

Seasonal patterns for the endemic and threatened birds along an elevational gradient were relatively similar, although even small differences may be relevant for conservation. Of the nine endemic species recorded, no significant differences were observed between seasons (W=100, p=0.2; Mean diff. =0.01; t=1.36; p=0.20). The proportion of endemics increased from approximately 60% at lower elevation (~3,300 m) to 90% between 4,000 m to 4,400 m, then declining to 20% at 4,700 m (Fig. 17). Of the seven threatened species that were observed, there were no significant differences between seasons (W=91 p=0.07; Mean diff. =0.01; t=1.73; p=0.08). However, unlike the endemics species, the proportion of threatened species observed increased markedly from 3,900 to 4,300 m, with 100% of these species detected between 4,300 and 4,500 m.

Finally, the community similarity measure (unweighted pair-group; UPGMA) distinguished three distinct clusters of species over the elevational gradient that persisted across seasons, although for each cluster, similarity was greatest during the dry season (Fig. 18). The avifauna at lower elevation (3,300 – 4,000 m) were most similar, clustering

together in ~90% of the bootstrapping (Boot N = 1000 times). Communities at mid-elevation (4,000 – 4,500 m) clustered together in 64%, while at higher elevations (4,500 – 4,700 m), the fauna remained as a distinct cluster in ~83% of the bootstrapping and were the narrowest elevational cluster.

DISCUSSION

High elevation glacial valleys in the Cordillera Blanca – Peru, support approximately 70-100 bird species, making the region among the most diverse ranges in the high Andes (>3,500 m) (Table 2). Patterns of species richness and community composition were comparable among the five glacial valleys, suggesting that many other valleys within the Cordillera Blanca may support similar communities. The high incidence of several endemic and globally threatened species associated with *Polylepis* forest reinforces Fjelda's recommendation that protecting centers of endemism along the Andes is critical to meet long term conservation objectives (Fjeldså, 1993).

Furthermore, estimates of species richness in the current study were notably higher than previous studies in the Andes (Table 2), and even higher than within Huascaran National Park. For example, my estimates of species richness exceed previous reports within Huascaran National Park by 67% in Ulta, 108% in Parón (Frimer & Møller-Nielsen, 1989), and 50-150% in other valleys (Fjeldså, 1987; Barrio, 2002; Sevillano-Ríos *et al.*, 2011). Although it is possible that the higher estimates of species richness might reflect real increase in bird diversity over time, I suspect that differences reflect our more intensive sampling methodologies. Although communities were dominated by a few common species (e.g., 10 species represented 50% of the observations), there were many rare species, which suggests that these and many other species could easily escape detection. Because few

studies conducted in the High Andes have explicitly considered detection probability (*p*) (Lloyd, 2008), sampling methodology in previous studies likely contributed to the lower estimates of species richness, particularly within *Polylepis* forest (Herzog *et al.,* 2002; Compañía Minera Antamina Asociación Ancash, 2004; Sevillano *et al.,* 2011; Tinoco *et al.,* 2013). Nevertheless, 40 years of protection and management in Huascaran National Park may have reduced anthropogenic pressure within the park enough to allow sensitive species to increase in numbers and/or colonize restored areas.

Seasonal patterns of species richness

There was a consistent pattern of greater species richness in wet compared to dry seasons, though the pattern became less pronounced with increasing elevation. Lower elevations (<3,800 m) showed the most pronounced differences with 29% more species in the wet than the dry season, perhaps because they were used by a broader range of species. Low elevation areas were dominated by *P. sericea* forest and dense shrublands, which likely provided diverse resources, especially in wet seasons. Nectarivores and frugivores were especially common during the wet season, which roughly corresponded with breeding seasons. The absence of many of these species during the dry season, suggests that species either shifted their elevational distributions (elevational movements) between seasons, or migrated during the most stressful conditions to other locations (Fig. 11 a-b). However, irrespective of the behavioral mechanism, the reduced species richness during dry seasons suggests that drier future conditions induced by climate change may negatively impact birds in the high Andes, particularly at lower elevations.

Although it is intuitive to expect large seasonal changes in bird communities at high elevations, this study found the opposite pattern – species richness above 3,800 m changed

relatively little between wet and dry seasons. The apparent seasonal stability of high elevation communities suggests that birds there may be better able to cope with drier future conditions. Interestingly, the numbers of endemic and threatened species were particularly stable across seasons. One possible explanation is that many birds of the High Andes are adapted to the highly variable conditions and stark seasonality at high elevations. For example, the Andean Hill-star (*Oreotrochilus stella*) has an impressive ability to enter a state of torpor to survive freezing temperatures in the high Andes (Pearson, 1953, Schuchmann *et al.,* 1983; Monge and Velarde, 1991; Wolf and Hainsworth, 1972). Other species (e.g. *Anairetes* Tit-tyrants) have a highly efficient hemoglobin-oxygen system for high elevations (Galen *et al.,* 2015; Projecto-Garcia *et al.,* 2013; DuBay and Witt, 2014).

My results suggest that elevational changes in distribution between seasons occur for specific species (See Appendix B and C). While many species maintain their elevational distributions between seasons (e.g. *Oreomanes fraseri; Poospisa alticola, Anairetes alpinus*), some species shift (e.g. *Oreotrochilus estella*), shrink (e.g. *Lesbia victoriae*), or expand their distribution (e.g *Zaratornis stresemanni*) between seasons (Appendix B and C). These flexible patterns suggest that species-specific responses to climate change are likely, with some species better able to adjust their elevational distribution/abundance to a set of more suitable conditions along an elevational gradient than others (Appendix E). However, this aslo implies that many species – especially endemics and threatened species– would be in trouble trying to adjust their requirements to new climatic conditions. For this vulnerable species, elevational shifts of the more flexible species might alter species interactions and increase extinction risk of less competitive and more specialized species, especially for those located at higher elevations (Moller *et al.,* 2004; Moller *et al.,* 2009). Understanding the underlying reasons for distributional shifts will require

population-level approaches as well as use of abundance or occupancy models that incorporate environmental covariates in the analysis of certain species (Royle and Nichols, 2003; Joseph *et al.,* 2009).

Because *Polylepis* forest at high elevations is the only type of forest and tends to have sharper borders with a high structural contrast with the Puna matrix (Chapter 4, Lloyd and Marsden, 2008), *Polylepis* fragments could be providing a refuge to many species and potentially buffering the harsh conditions outside of them. Given that Cordillera Blanca is a relatively dry range (United Nations Environment Programme - World Heritage Sites, 2008), temperature stability and water availability are likely to be the main determinants of bird diversity along elevational gradients there, as has been demonstrated elsewhere (MCain, 2009). Within this context, *Polylepis* forest at upper elevations, tends to be more humid and to maintain more stable temperatures compared to the matrix (Kessler, 2006; Jameson and Ramsay, 2007), which might explain why it can support high numbers of species throughout the year, a pattern that is true not only for birds but also for plants (Servat, 2006). In this way, *Polylepis* forest might provide a refuge that could partly ameliorate the drier future conditions expected under changes in climate. This would be important, not only for maintaining bird diversity, but also for providing different vital ecosystems services (e.g., water supply) to local human communities.

Species richness along elevation

One of the most notable findings of this study was that species richness peaked at mid-elevations, around 4,000 m, rather than declining across the entire elevational gradient (Gaston, 2000). This pattern is congruent with previous results or predictions proposed in other regions (Patterson *et al.,* 1998; Kattan and Franco, 2004), although the mechanisms

remain poorly understood. Proposed mechanisms include the Mid-domain effect (McCain, 2004), ecotone effect (Terborgh, 1977, 1985), intermediate levels of disturbance (Petraitis *et al.,* 1989), evolutionary history (McCain, 2009), and even sampling bias (McCain and Knight, 2013).

The mid-domain effect predicts that richness is greatest at mid-elevations due to higher overlap of species distribution ranges at the center, but not extremes of environmental gradients (Colwell *et al.,* 2004, 2005; McCain, 2009). Indeed, in this study, species that occupied the lowest (<3,500 m) or highest (>4,400 m) elevations exhibited the narrowest elevation ranges, whereas most species with range medians at mid-elevations showed wider distributions (Fig. 19). Patterson *et al.,* (1998) also found a similar pattern for the bird community in southern Peru, suggesting that species occurring at elevational extremes have less environmental tolerance and, hence, occupy narrow niches, especially at upper elevations. In Cordillera Blanca, three of the most *Polylepis* specialized and threatened birds, the Ash-breasted Tit-tyrant (*Anairetes alpinus*), White-cheeked Cotinga (*Zaratornis stresemanni*) and the Tawny-Tit-tyrant (*Leptasthenura yanacensis*), were restricted to the highest elevations. The Ash-breasted Tit-tyrant had the narrowest distribution from 4,400 to 4,600 m, with 50% of observations from 4,450 m to 4,520 m, which likely contributes to their vulnerability (Chapter 4). These observations contrast with the extension of "Rapoport's rule" (Rapoport, 1982) to elevation gradients (Stevens, 1992), which states that as elevation increases, species occupy broader elevational ranges by having greater tolerance and wider niches. However, a recent meta-analysis across a wide variety of taxonomic groups and geographic areas found that Rapoport's rule was supported in only half of the studies of birds (McCain and Knight, 2013).

Another potential explanation for the observed richness pattern is that habitat heterogeneity due to plant communities, transitional habitats, or ecotones (Lomolino, 2001) peaks at mid-elevations and, consequently, promotes higher bird diversity. This scenario does apply to my system, in which the forest transitions from *Polylepis sericea* to *P. weberbaueri* and grasslands and shrublands become more common at ~4,000 m (this study, Chapter 4).

My findings are consistent with Lomolino (2001), who predicted that a mid-peak species richness pattern is more likely in isolated mountain systems, where patterns of endemism should peak toward mid to upper elevations. These mid-peak species richness pattern would be caused by the combined but opposite effect of isolation, speciation and extinction rate, that tend to increase with elevation, and immigration and anthropogenic disturbance that decrease (Lomolino, 2001). A study from Colombia was consistent with this idea, but added the idea of a strong mass effect on Andean slopes connected to Amazonia. They revealed that the mid-peak pattern was more frequently observed in elevational gradients in the interior of the Andes, where endemism is fairly high and the area is distant from lowland Amazonian habitats, whereas diversity decreased with elevation on mountains that were connected to lowland Amazonian habitats (Kattan and Franco, 2004). Inflated species richness at lower elevations and sharp diversity gradients with elevation are not observed in interior Andean slopes (Kattan and Franco, 2004). Thus, a mid-elevation peak in richness might reflect the fact that Cordillera Blanca is an isolated and interior Andean mountain system that lacks direct connection with Amazonian habitats or other diversity hotspots that might inflate the number of species at much lower elevations (<3,300 m).

This study provides a foundation for understanding patterns of species richness across seasons and elevational gradients in one of the world's most vulnerable areas to climate change. From a conservation perspective, my work provides several key insights. First, given the much higher estimates of species richness than previous studies, and in the face of continuing development in the Andes (e.g. roads, mining, dams), my findings suggest that future studies, including Environmental Impact Studies (EIAs), should incorporate the detection probability (*p*) estimation for a more reliable assessment of the community (Royle and Dorazio, 2008). Otherwise, the non-detection of the most rare and threatened species would preclude their consideration and negatively affect conservation. Second, my work shows that contrary to widespread expectations, high elevation habitats can be species rich and support many endemic and threatened species. Third, seasonal shifts in species richness, specifically sharp reductions during dry seasons – imply that the projected warmer and drier conditions in the region might negatively impact certain species. Fourth, the presence of *Polylepis* forest was associated with fewer seasonal shifts among birds, which suggests that the habitat might provide important refuge or buffering against future climate change. Future investigations of the drivers of diversity patterns are crucial to better understand the effects of climate change on mountain ecosystems. Studies of altitudinal movements of priority bird species, combined with coordinated monitoring, will provide important insights into the response of bird populations to climatic changes, and will help to inform conservation of biological diversity in the High Andes.

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TABLES

Table 2. Studies on *Polylepis* bird communities conducted along several Andean localities. Species richness is shown next to locality names.

Studies	Species Richness per localities
Jon Fjeldså 1987	Cordillera Blanca, Ancash and Cordillera Vilcanota, Cuzco. Pucavado: 43; Urubamba: 57
Frimer & Moller 1989	Cordillera Blanca, Ancash Rurichinchay: 50; Ulta:44; Rurec:43; Carhuascancha:37; Paron: 36; Ishinca:35; Shallap: 19
Jon Fjeldså 1993	Puquio, Ayacucho: 33; Quishuarnioc, Arequipa: 29; Palmera, Ayacucho: 25; Runtacocha, Apurimac: 36; Pueblo Quichas: 43; Pariamarca, Pasco: 37.
Maynard, Emily. 1998.	Cordillera Huayhuash, Ancash and Lima. Huamanhuque: 27; Maca Ragra: 39; Rariash: 32; Cuncush: 33; Quenquen: 31; Mancan: 40; Matibamba:30
Balderrama & Ramirez 2001	Parque Nacional Tunari, Cochabamba Bolivia San Miguel: 57; PT km12: 51
Servat et al 2002	Cordillera Vilcanota, Cusco. Sacsamonte: 43; Yanacocha: 60; Pumahuanca: 40; Queñuamonte:34
Barrio 2002	Cordillera Blanca, Ancash
Ferro et al 2004	Cordillera Vilcanota, Cusco. Abra Málaga: 36; Cancha Cancha: 45; Quishurani: 34; Choquechaca:39; Huilloc-Queñuacocha:42
ECOAN 2005	Conchucos, Ancash Tacarpo: 35; Gague:41; Pachac:45; Yanacocha:42; Pumahuain:39; Chacac Monte:38; Canrash:54; Juprog:58; Pachapaqui:40; Huinco:44; Jupaymarca:51; Huamanhueque:39
ECOAN 2006	Puno. Lawa Lawani:33; Chingo:35; Torno:28; Bellavista:29; Quilcapuncu:25
ECOAN 2007	Otishi National Park, Ayacucho Muyuorco: 50;Yanaorco: 25
Lloyd & Marsden 2008	Cordillera Vilcanota, Cuzco, Peru. Mantanay: 43.2;Yanacocha: 43.1;Huilloc: 38.7; Total: 54.4
Ferro & Santander 2009	Chumbivilcas, Cuzco: 49
Benham et al 2011	Apurimac. Anantay 52
Sevillano et al 2011	Cordillera Blanca, Ancash Peru Aquillpo: 31; Gague:32; Rurichinchay:26; Huamanhueque:16; Demanda: 29
Tinoco et al 2013	Cajas National Park, Ecuador: 30
Meneses & Herrera 2013	Boyaca, Colombia. Paramo de la Rusia: 34
This study	Cordillera Blanca, Ancash Paron: 92; Llanganuco: 96; Ulta: 97; Llaca:81; Rajucolta: 72

Table 3. Number of species observed S(*obs*) by # individuals observed. The extrapolation curve was set to 3,500 individual on Paron, Llanganuco and Parón, while for Llaca and Rajucolta, it was set to 2,500 ind. ACE Δ is the species number difference between seasons estimated by the asymptotic estimator ACE.

Study Area	S(*Obs*)/# Ind	Extrapolation curve (SD)	ACE (SD)	ACE Δ Wet-Dry Season
Parón				
Total	85/2672	92.41(5.65)	91.68 (0.35)	
Dry Season	66/750	70 (3.52)	71.45 (0.55)	14.11
Wet Season	75/1922	78.96 (4.64)	85.56 (0.3)	
Llanganuco				
Total	89/4055	95.11 (4.44)	95.63 (0.34)	
Dry Season	64/988	74.73 (7.18)	73.44 (0.84)	16.49
Wet Season	82/3067	82.67 (2.12)	89.93 (0.2)	
Ulta				
Total	89/4344	101.75 (7.39)	96.74 (0.3)	
Dry Season	73/1267	78.88 (4.55)	78.56 (0.39)	5.35
Wet Season	77/3077	77.56 (3.02)	83.91 (0.49)	
Llaca				
Total	66/2136	90.16 (14.34)	81.15 (0.63)	
Dry Season	46/610	66.09 (12.24)	52.88 (0.64)	11.8
Wet Season	57/1526	61.74 (3.7)	64.68 (0.21)	
Rajucolta				
Total	72/3730	72 (0.01)	72 (0.06)	
Dry Season	60/1660	60 (0.01)	60 (0.66)	16.8
Wet Season	64/2070	66.42 (3.95)	76.8 (0.48)	
Total Across sites				
Dry Season	97/5756			
Wet Season	104/11658			

Table 4. Regression models for the species richness pattern along the elevational gradient of Cordillera Blanca, Peru during 2014-2015 seasons using point count data only or with systematic additional observation. I used a forward model selection based on R2, p, and AICc criteria. PC: Point Count Data; PC+: Point Count Data plus

Data	Season	Order	Equation	R^2	*p*	AICc
PC	Dry	1st	0,01299x-14,63	0,137	0,193	2431,3
		2nd	$-5{,}992E\text{-}05x^2+0{,}4923x-963{,}5$	0,508	0,020	1390,3
		3th	$-4{,}91E\text{-}08x^3+0{,}0005293x^2-1{,}85x+2122$	0,538	0,044	1309,9
	Wet	1st	-0,000154x+50,3	0,000	0,986	1962,5
		2nd	$-2{,}222E\text{-}05x^2+0{,}1776x-301{,}6$	0,073	0,657	1822,1
		3th	$-7{,}816E\text{-}08x^3+0{,}0009157x^2-3{,}551x+4610$	0,182	0,549	1612,3
PC+	Dry	1st	-0,006073x+74,23	0,024	0,584	4264,7
		2nd	**$-8{,}885E\text{-}05x^2+0{,}7048x-1331$**	**0.770**	**0,000**	**1010,9**
	Wet	1st	-0,02038x+142,5	0,210	0,086	4383,7
		2nd	**$-7{,}373E\text{-}05x^2+0{,}5694x-1023$**	**0,615**	**0,003**	**2144,4**

FIGURES

Fig. 3 Four principal patterns of species richness along elevation were described along mountain ecosystems (McCain, 2009).

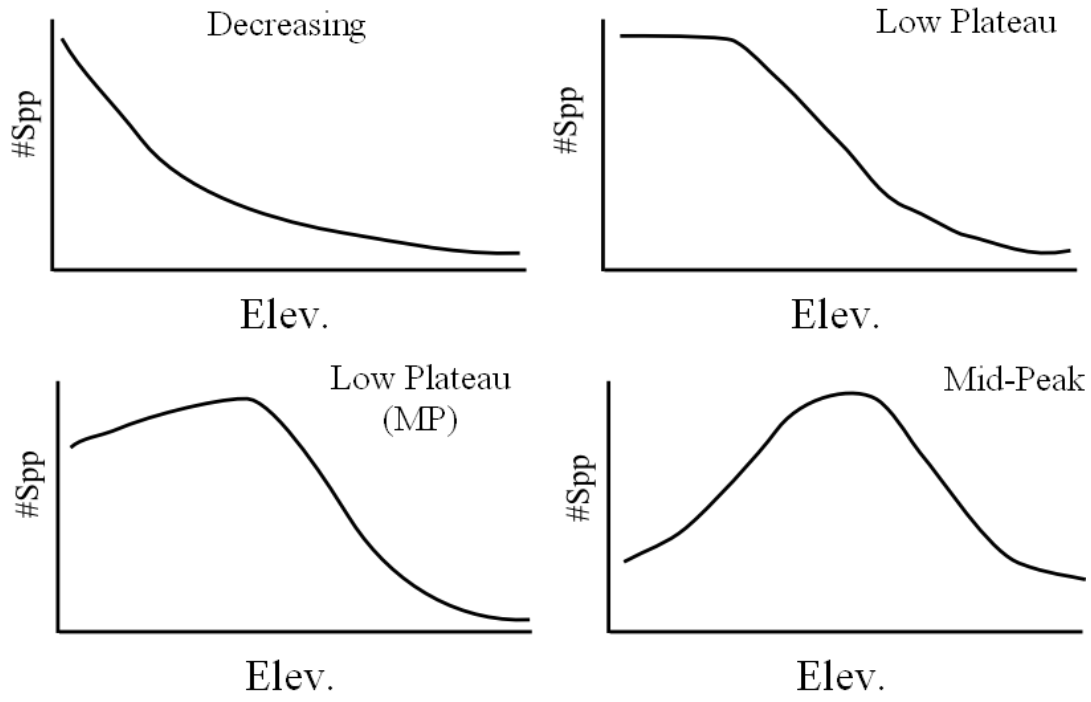


Fig. 4. Location of the study area – Cordillera Blanca, Ancash Peru. The green areas are *Polylepis* woodlands along Cordillera Blanca and protected by Huascaran National Park. Some *Polylepis* woodlands remain unprotected in Cordillera Huayhuash (southern section).

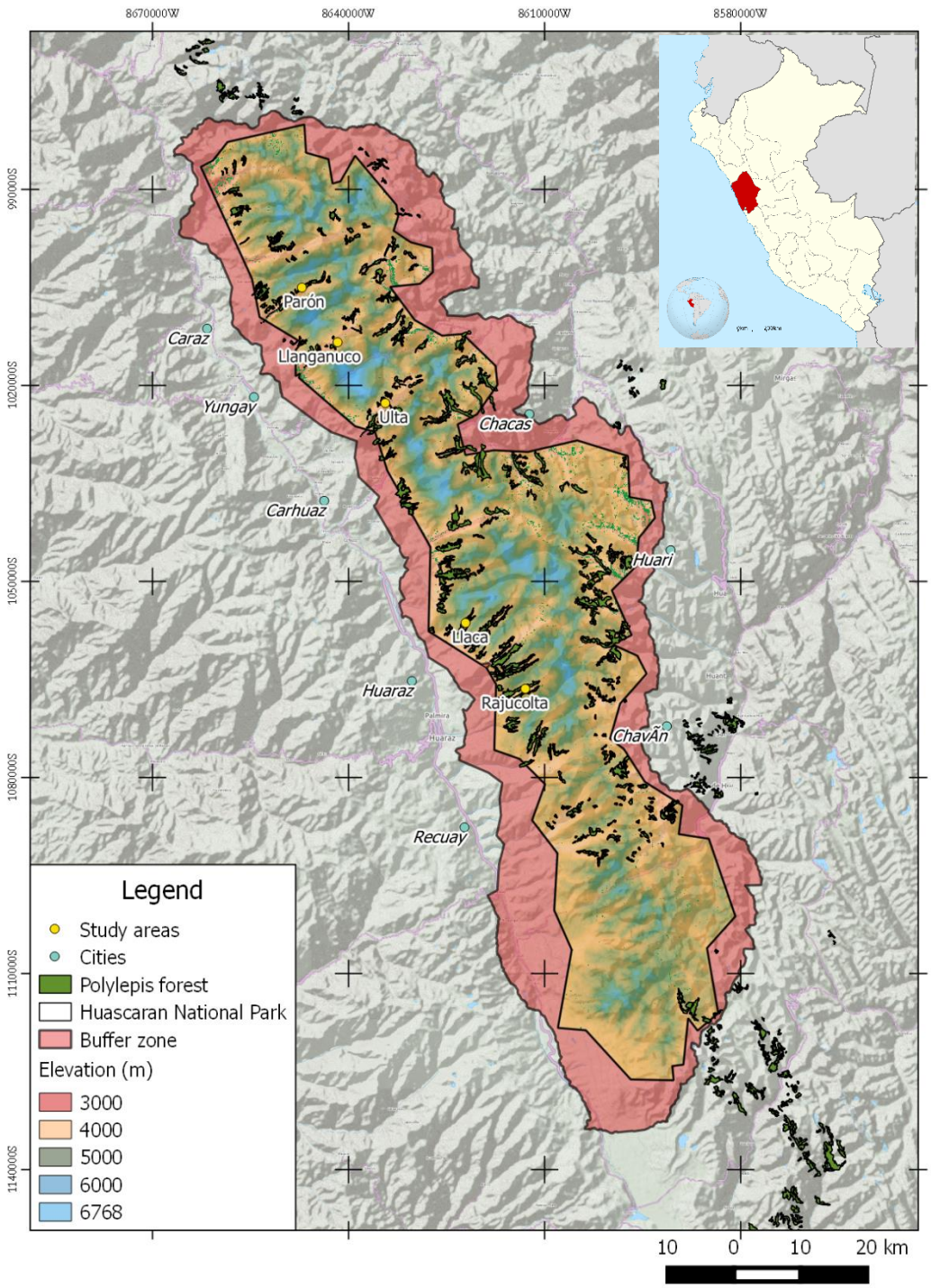
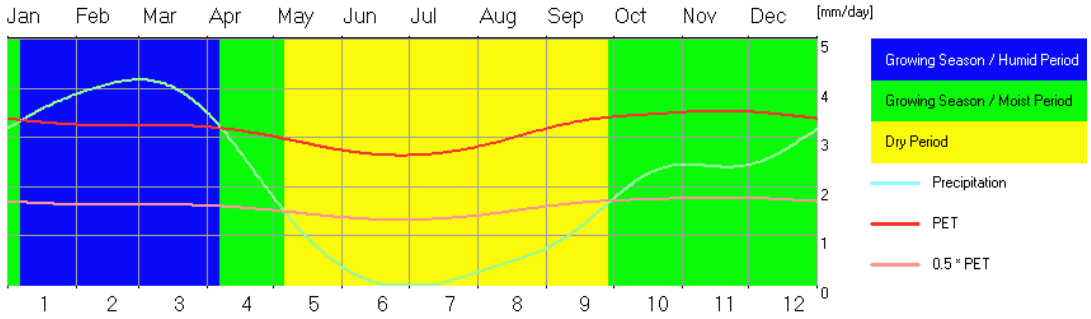
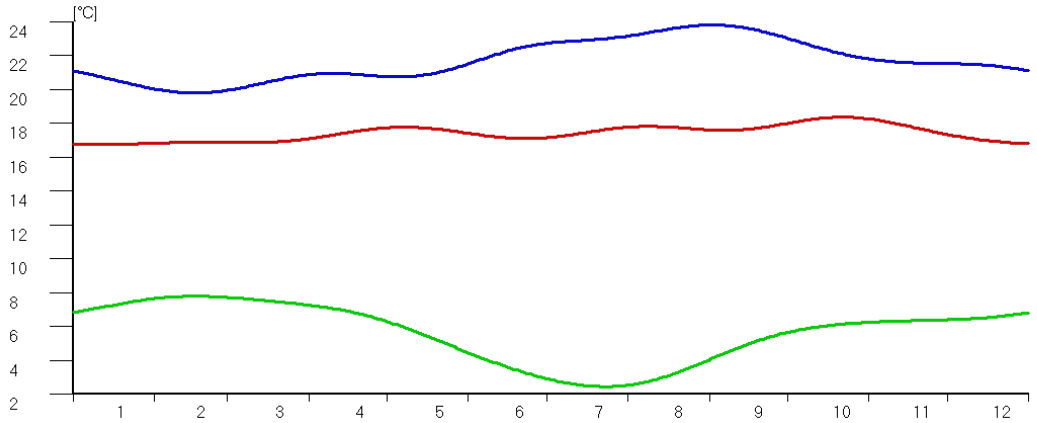


Fig. 5. Climatic information base on 15 meteorological stations around Huascaran National Park. Local vegetation growing period, precipitation (mm.) and Potential Evapotranspiration (PET) (a); daily maximum, minimum and mean air temperature in Celsius (°C) collected by the FAO (b) and sunshine fraction (%) (red), Day length (h) (green) and sunshine hours (blue).

a) Local vegetation growing period



b) Temperatures (°C)



c) Sunshine

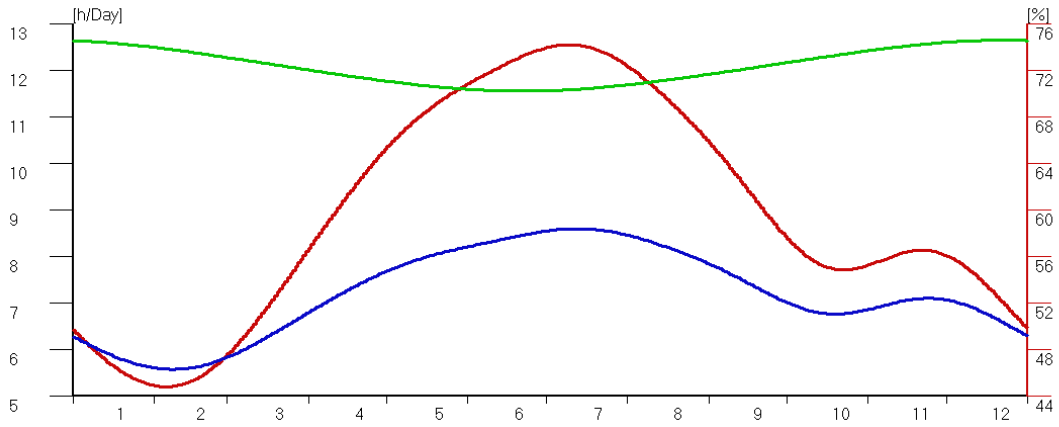
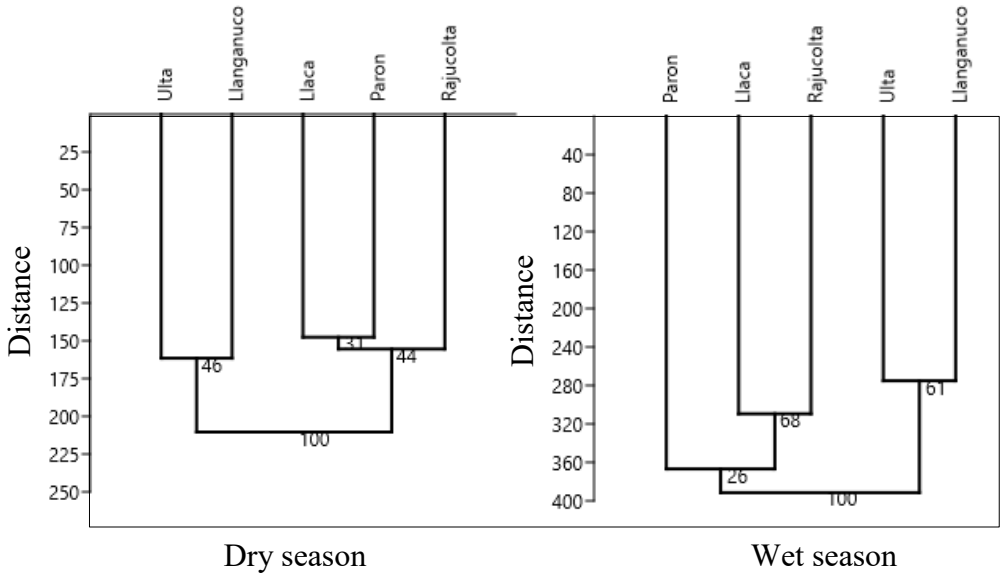


Fig. 6. UPGMA similarity analysis of the bird community among study sites between seasons. Values at the nodes are percentage of times that the node was maintained in the bootstrapping (N: 1000 times).



Dry season Wet season

Fig. 7. Species richness accumulation curve of the asymptotic abundance-coverage estimator (ACE) based on total number of individual birds observed over the wet and dry seasons in each of the five glacial valleys witin Huascaran National Park, Peru.

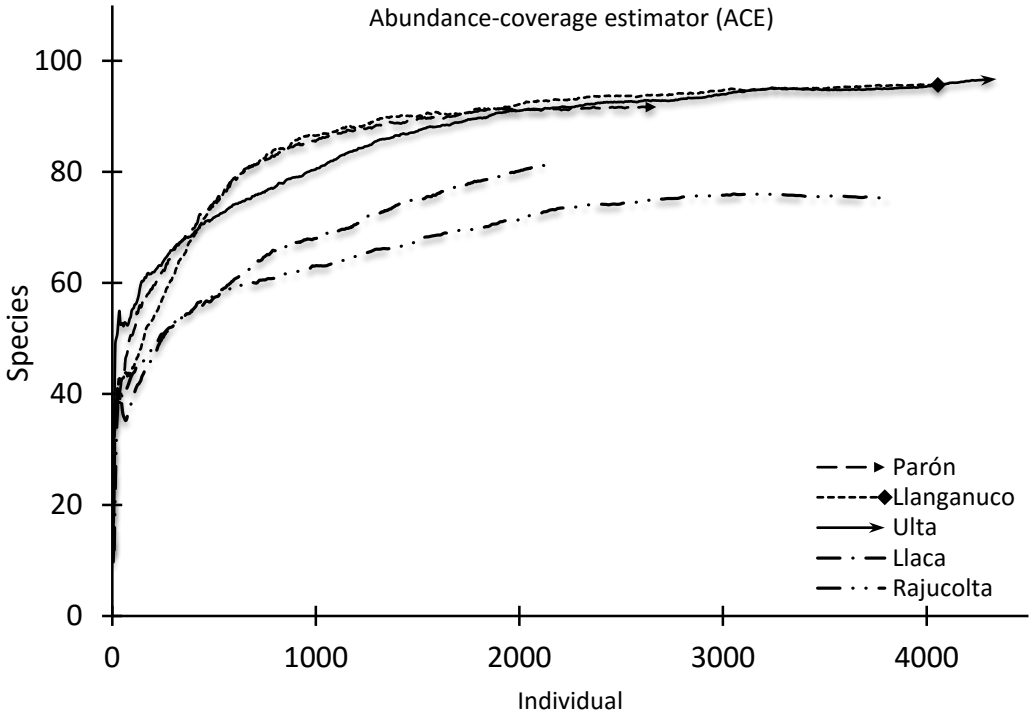


Fig. 8. Relative abundance pattern of the *Polylepis* bird community in Cordillera Blanca, Peru. Tit-like Dacnis (*Xenodacnis parina*) was the most common species recorded over both seasons and along an elevational gradient within five glacial valleys in Cordillera Blanca, Peru.

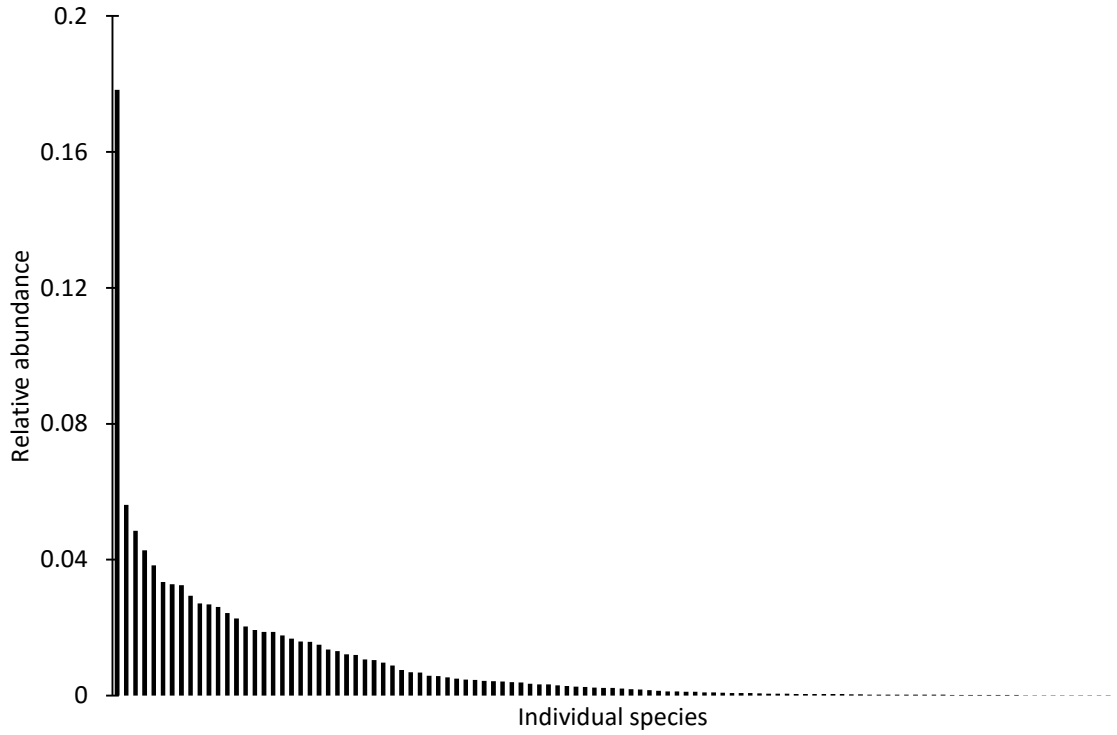


Fig. 9. The ten most common species observed in each season remained relatively constant in Huascaran National Park, Peru. Five were endemic species (*), including the near-threatened Rufous-eared – Brush-finch (*A. rufigenis*)

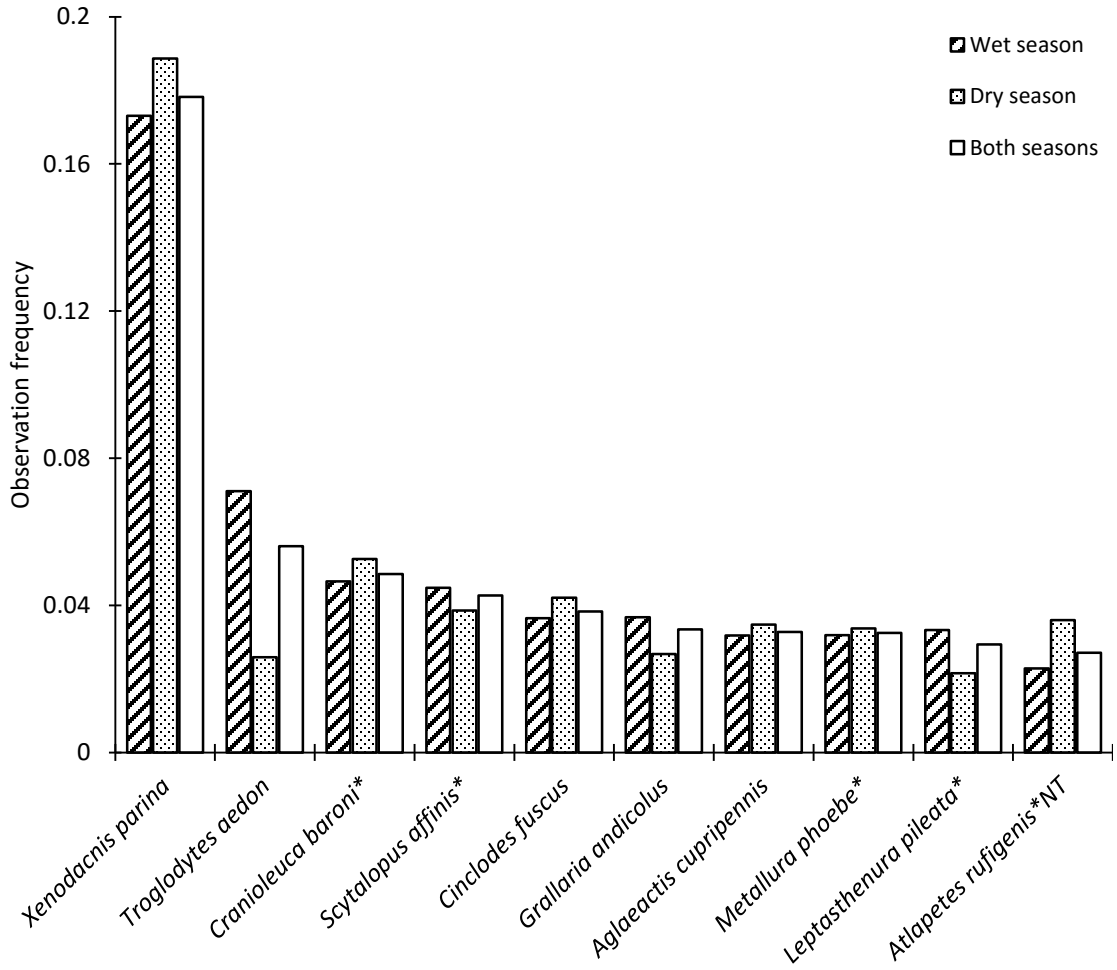
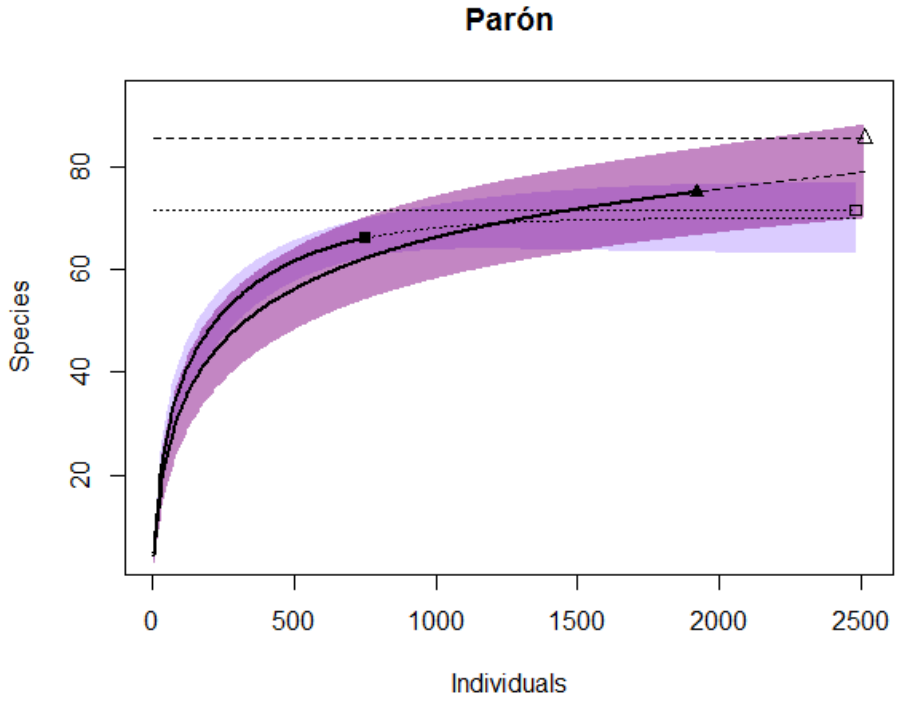
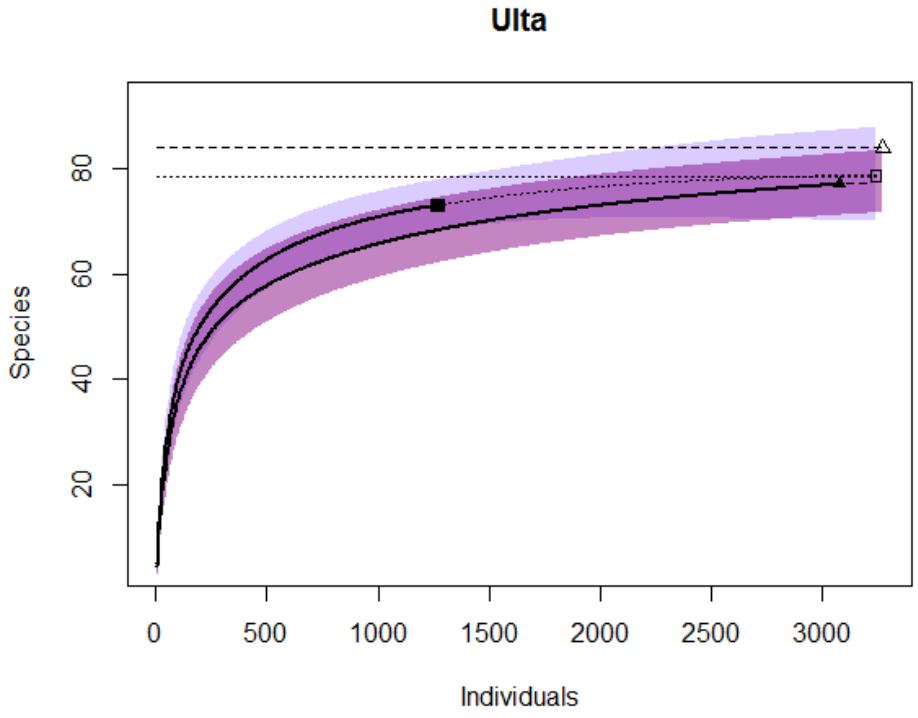


Fig. 10. Species richness accumulation curves along five glacial valleys in Cordillera Blanca, Peru. Curves are based on interpolation (solid) and extrapolation (dashed) rarefaction analysis taking into account the seasonal variation of observed species richness S(*Obs*) during the dry (■) and wet season (▲). Shaded areas represent the 95% confidence interval, while the asymptotic species richness (horizontal lines) is based on ACE analysis S(*est*) for dry (□) and wet season (Δ).

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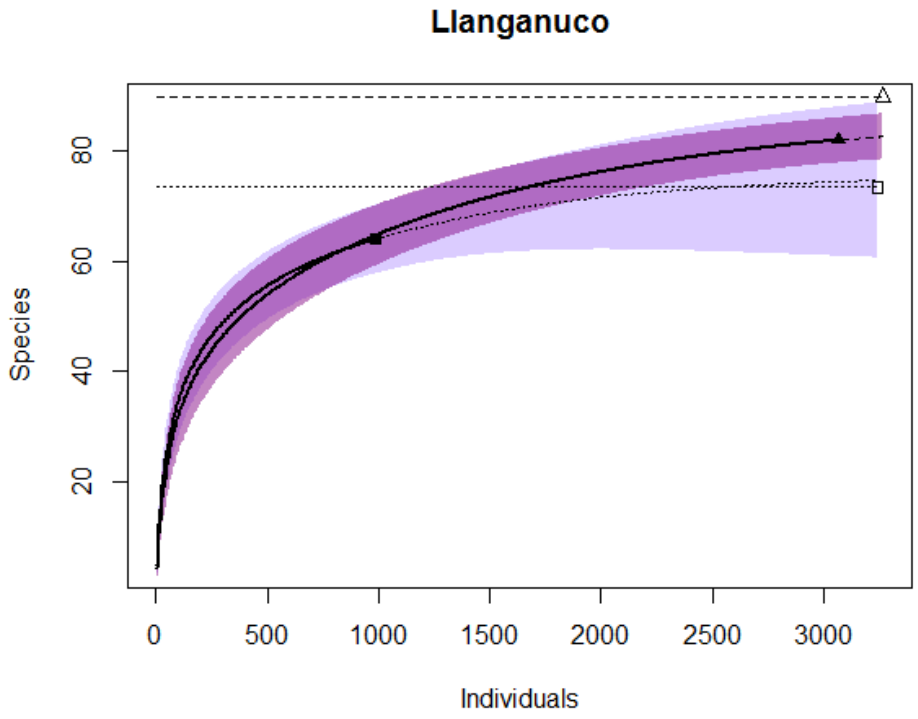
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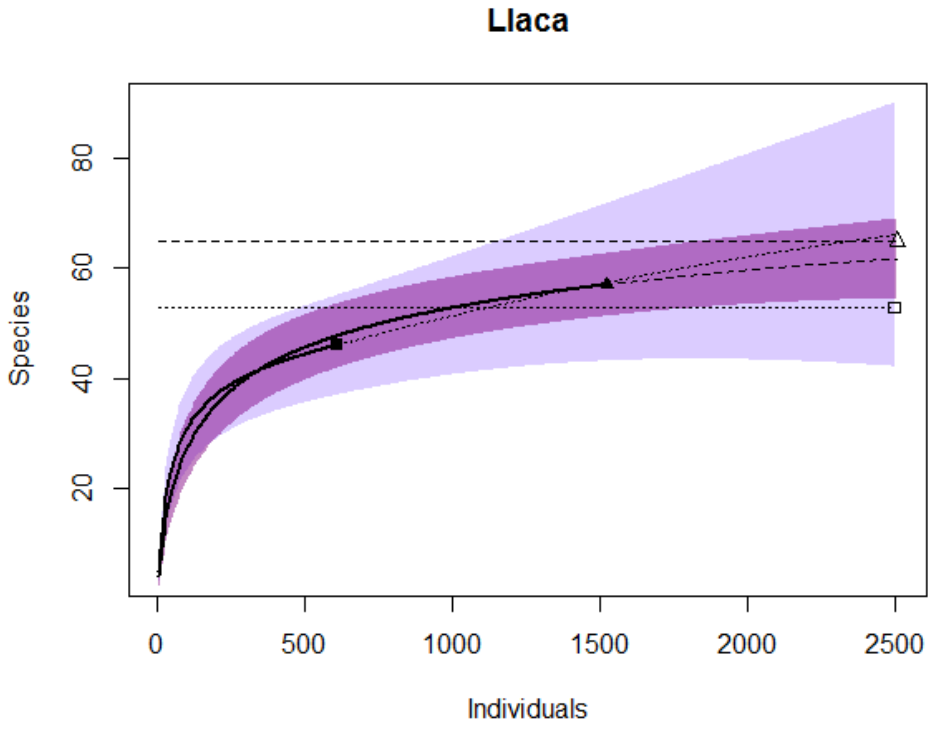
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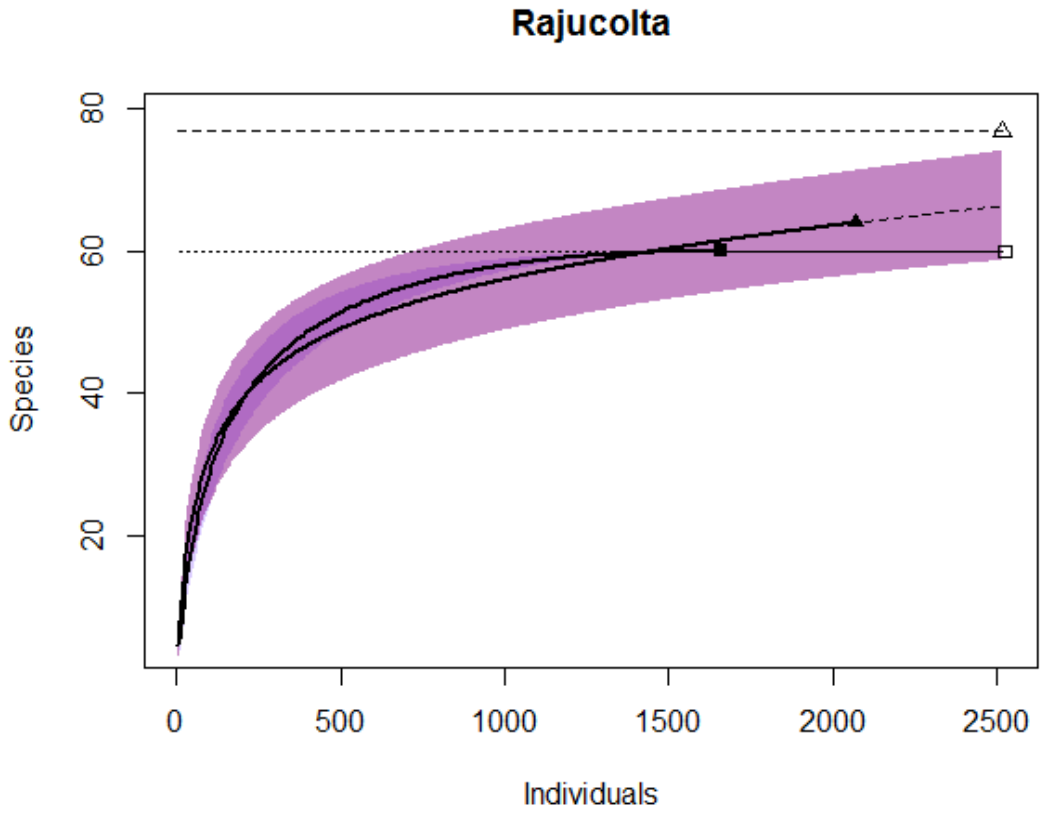
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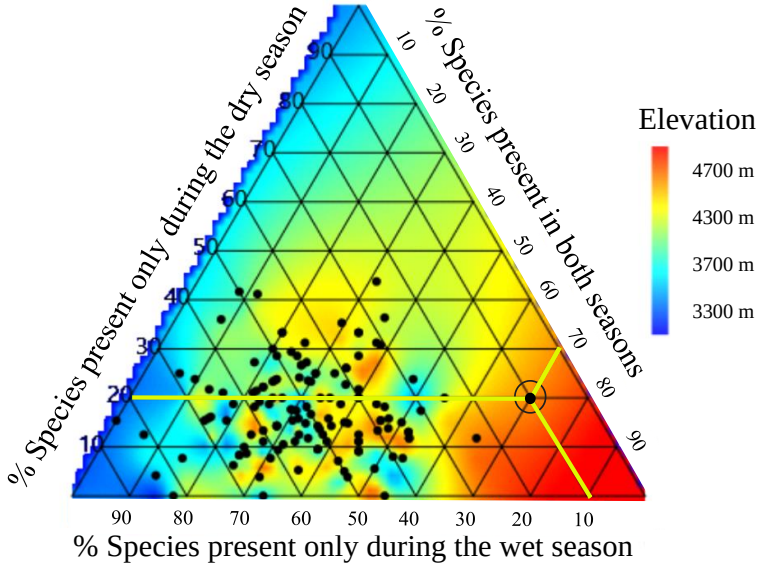
Fig. 11 Seasonal species turnover along with elevation in Huascaran National Park, Peru.

a) Proportions of species present only during one or both seasons (dry/wet) at each of the 130 point counts surveyed. For example, in the point count #24 of Loc 2 (the point inside the circle at 4,500 m), 70% of the bird species were present during both seasons, whereas 20% and 10% of the species were only present during the dry and the wet seasons respectively.



b) Boxplot of the proportions during the dry, wet, and both seasons along an elevation in Huascaran National Park, Peru.

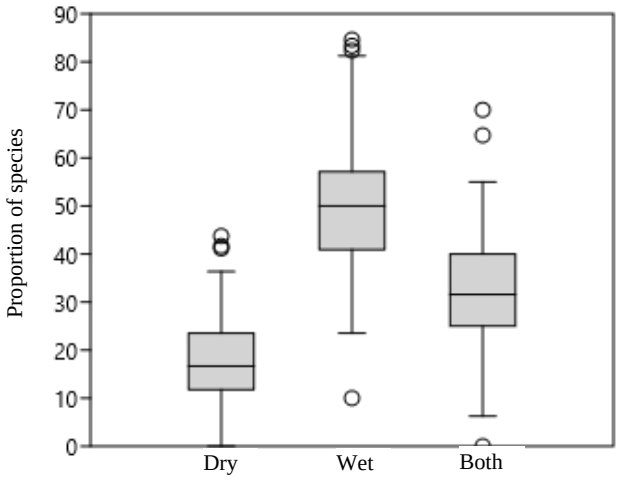


Fig. 12. Seasonal species number mean and SD observed S(*obs*) among point counts grouped by 100 m elevation bands at Cordillera Blanca, Peru.

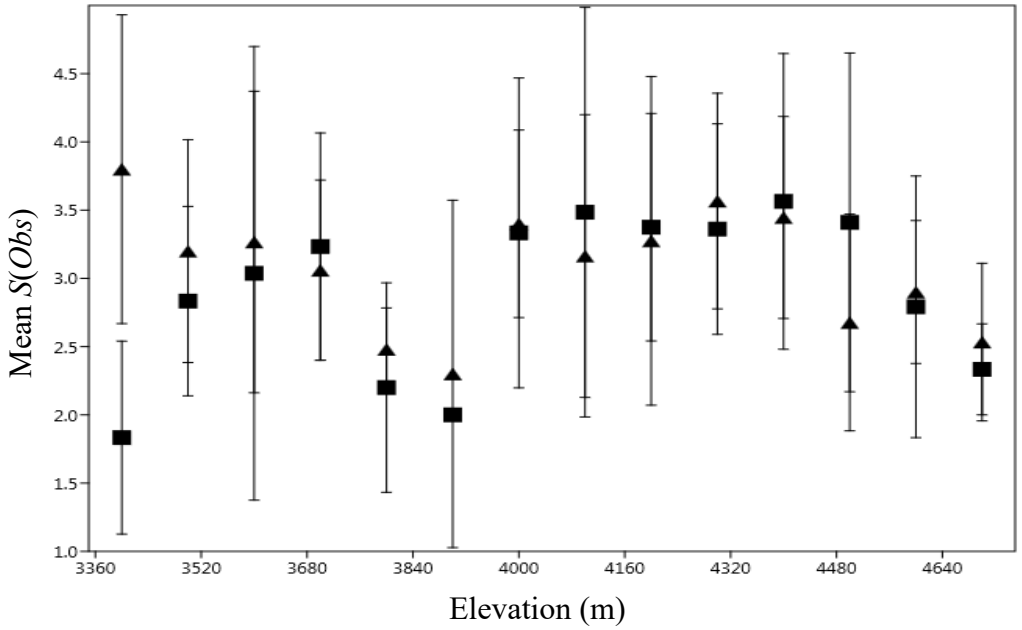


Fig. 13. Seasonal number of species observed S(*obs*) per elevation band; using point counts plus supplementary observations at Cordillera Blanca, Peru.

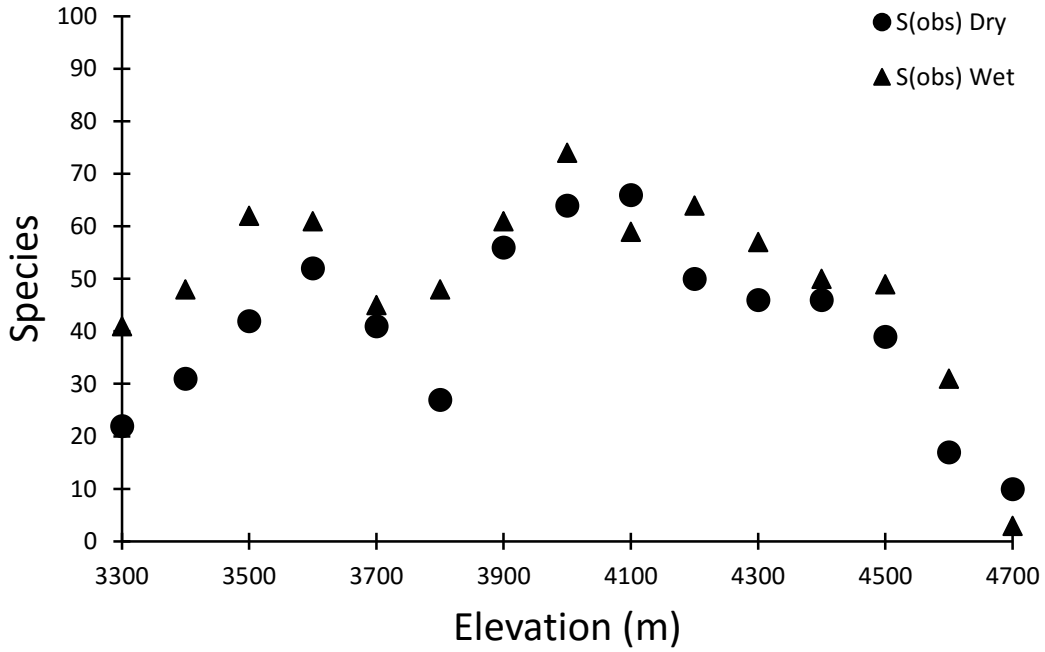
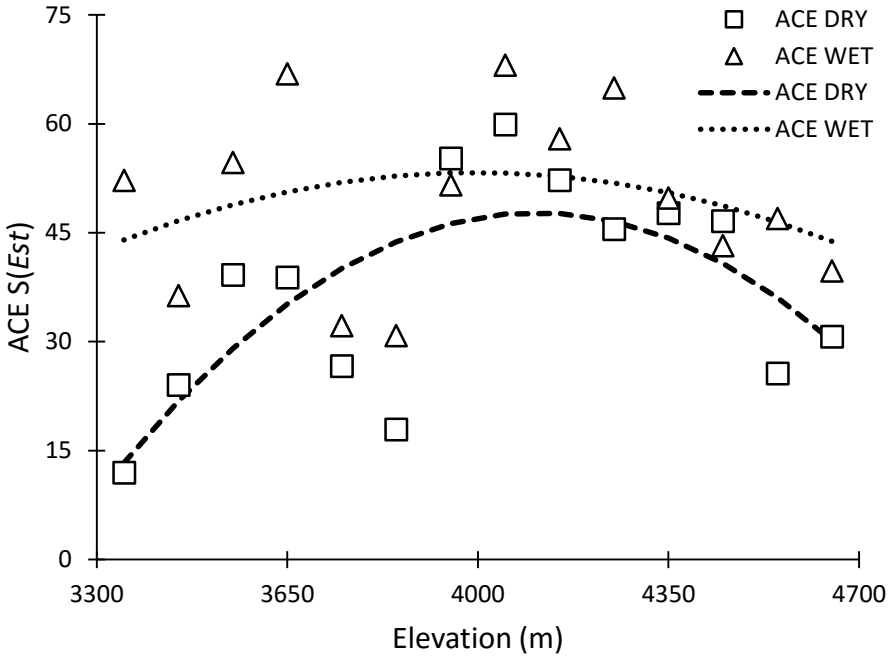


Fig. 14. Asymptotic species richness ACE estimated S(*est*) based on point count observations only (a) and the total core of observations (b) along 100 m elevation bands between dry (□) and wet (Δ) seasons at Cordillera Blanca, Peru.

a)



b)

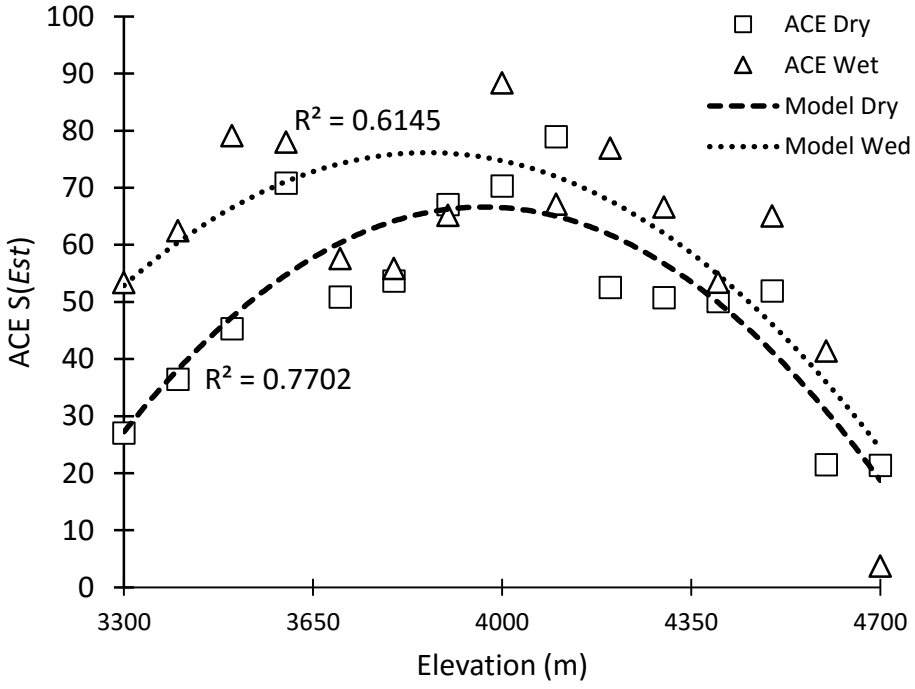
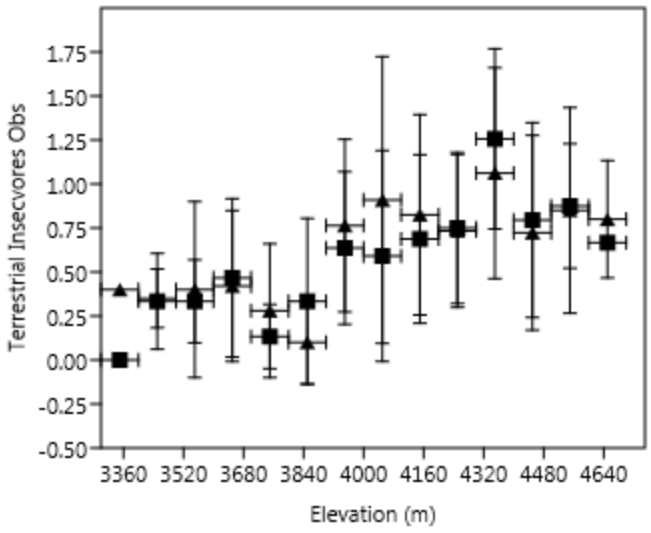
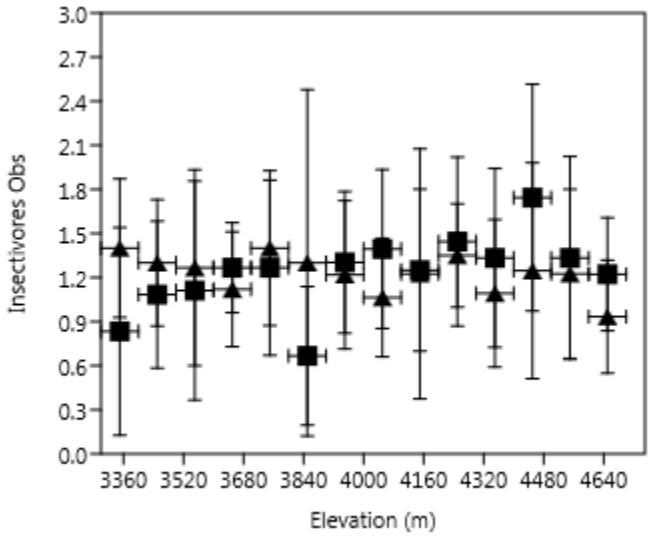


Fig. 15. Mean number of species of particular foraging guilds observed S(*obs*) (mean and SD) during the dry (■) and wet (▲) season at 100-m elevation bands at Cordillera Blanca, Peru.

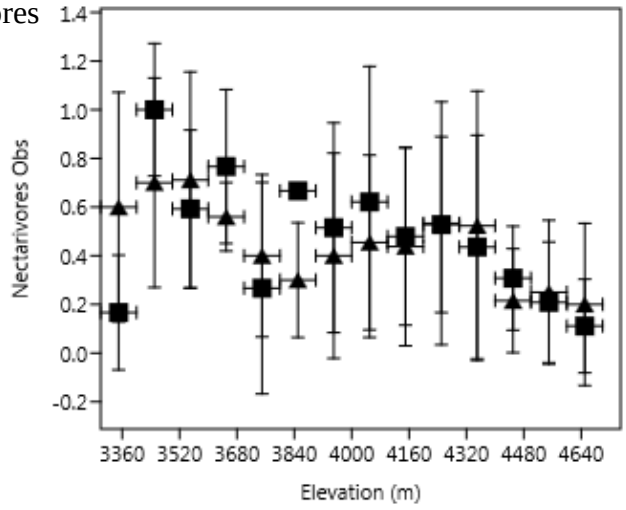
a) Terrestrial insectivores



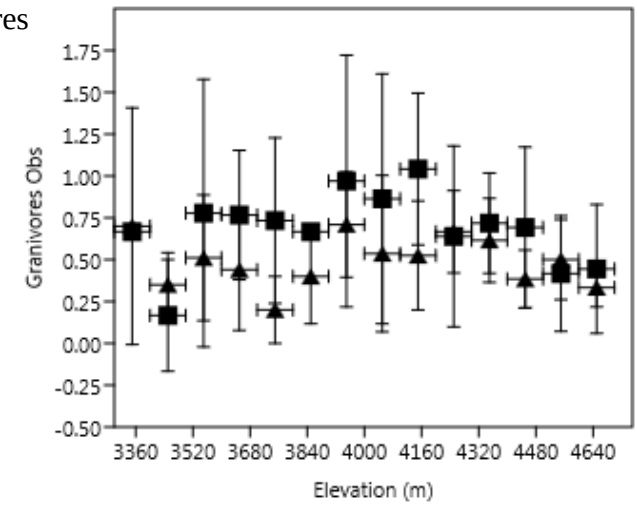
b) Aerial insectivores



c) Nectarivores



d) Granivores



e) Frugivores

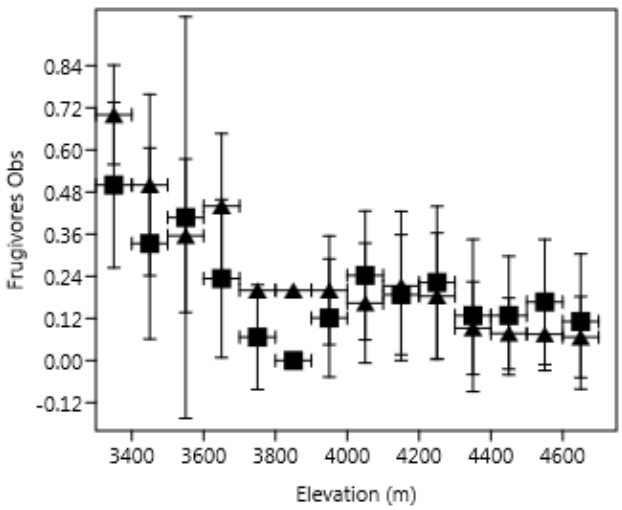
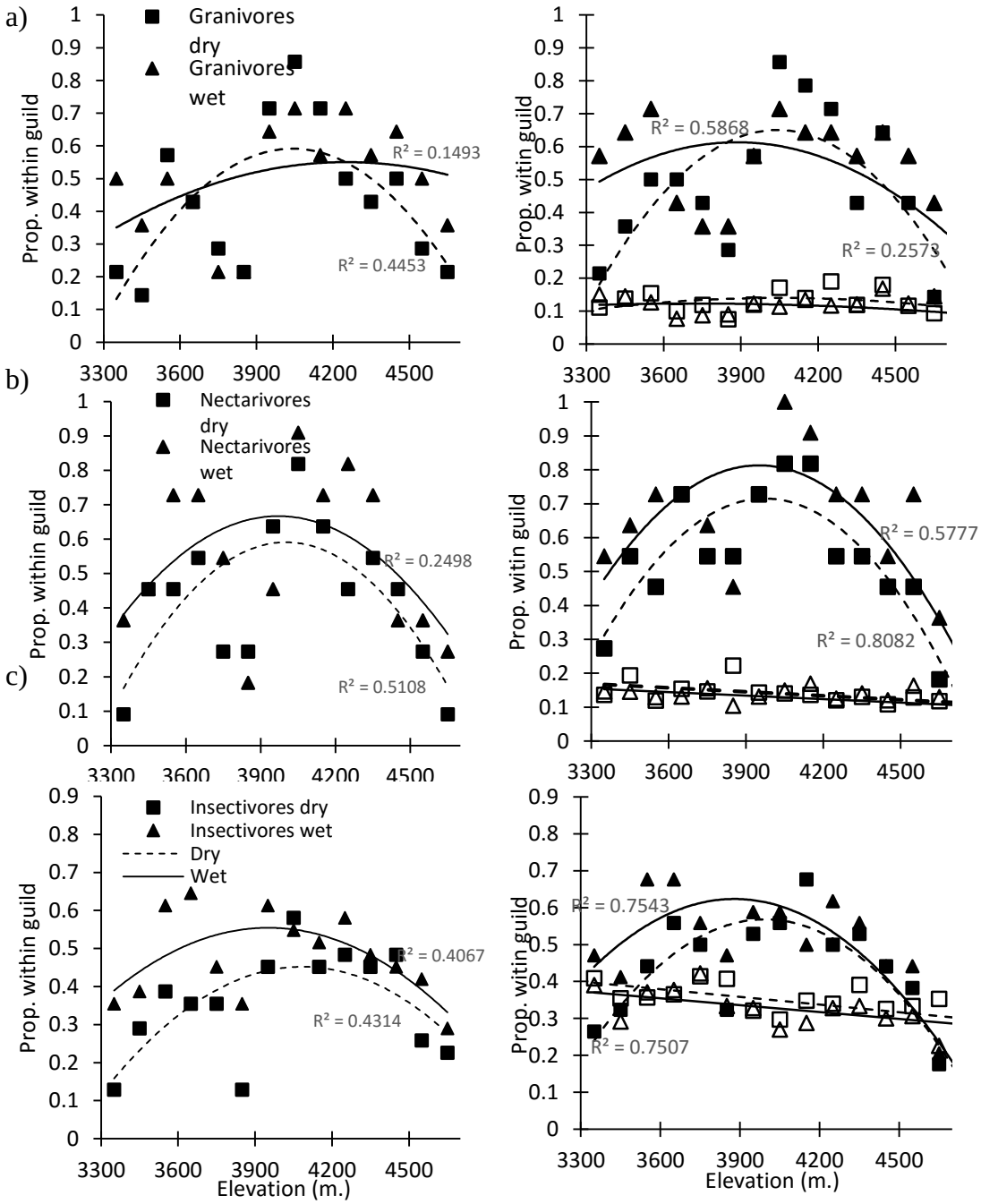
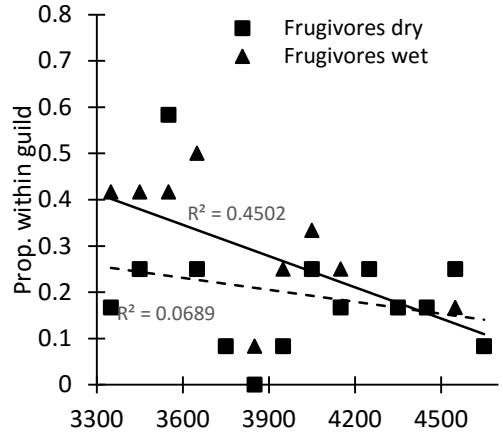
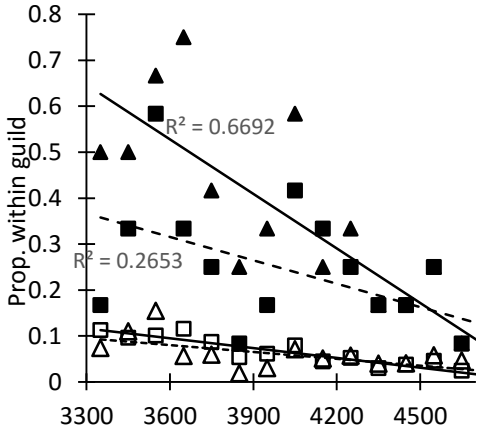


Fig. 16. Proportions of species for each foraging guild observed during the dry (■) and wet (▲) seasons at each elevational band, based on point count only (left), and point count with systematic observation (right) at Cordillera Blanca,Peru. Lines are best model fits for the data. Open symbols (□ and Δ) are the proportion of species that a particular guild represents in the whole community at an elevation (e.g. Granivores represent ~10% of the whole community at 3,300 m).

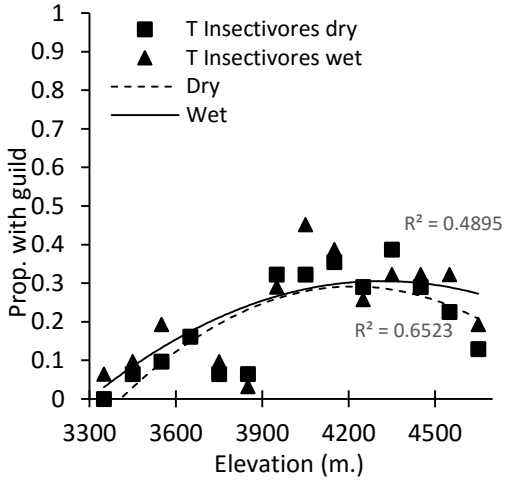


d)


Frugivores dry
Frugivores wet
Prop. within guild
R² = 0.4502
R² = 0.0689
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3300
3600
3900
4200
4500


Prop. within guild
R² = 0.6692
R² = 0.2653
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3300
3600
3900
4200
4500

e)


T Insectivores dry
T Insectivores wet
Dry
Wet
Prop. with guild
R² = 0.4895
R² = 0.6523
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3300
3600
3900
4200
4500
Elevation (m.)

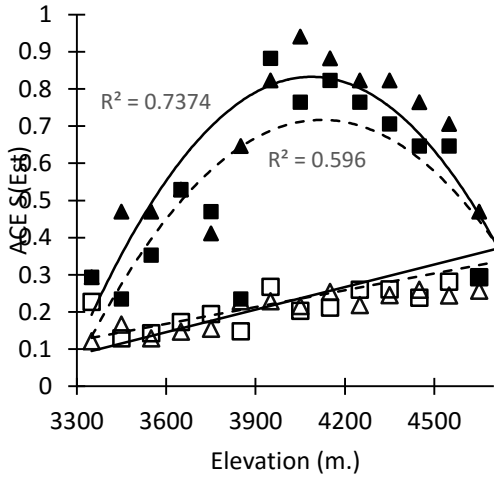

ACE S(Est)
R² = 0.7374
R² = 0.596
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3300
3600
3900
4200
4500
Elevation (m.)

Fig. 17. Proportion of endemic (left) and threatened (right) species at an elevation band, based on the total of observations. Nine endemic and six threatened species were recorded.

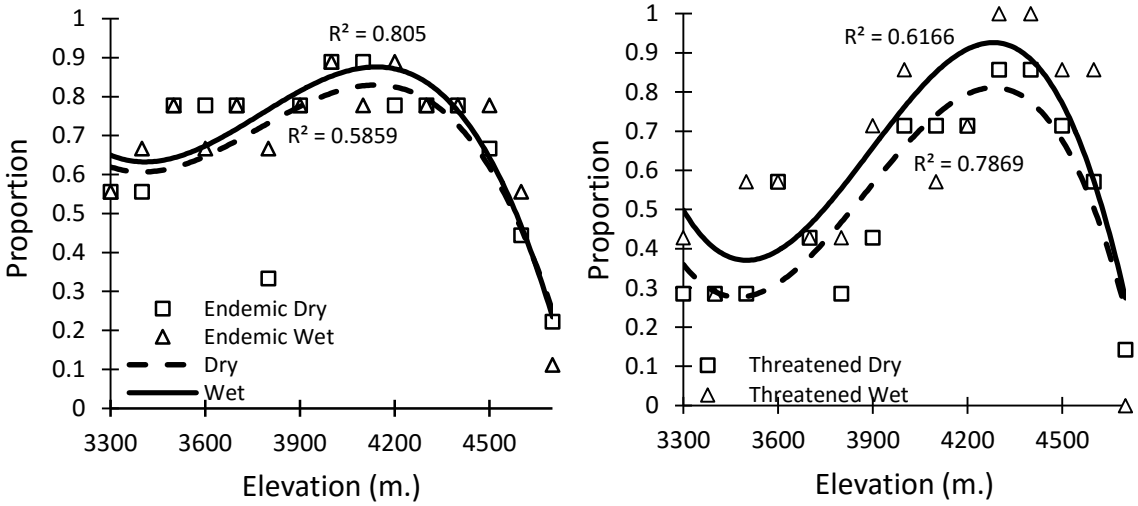


Fig. 18. UPGMA similarity analysis for the dry (left) and wet (right) season using the Euclidean similarity index constrained by elevation. Values at the nodes are percentage of times that the node was maintained in the bootstrapping process (N = 1000 times).

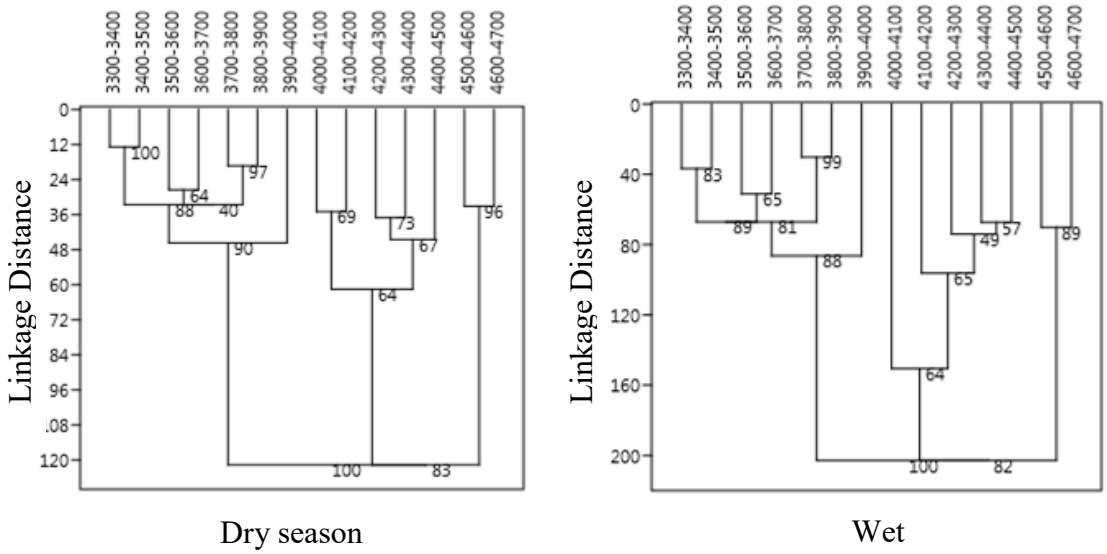
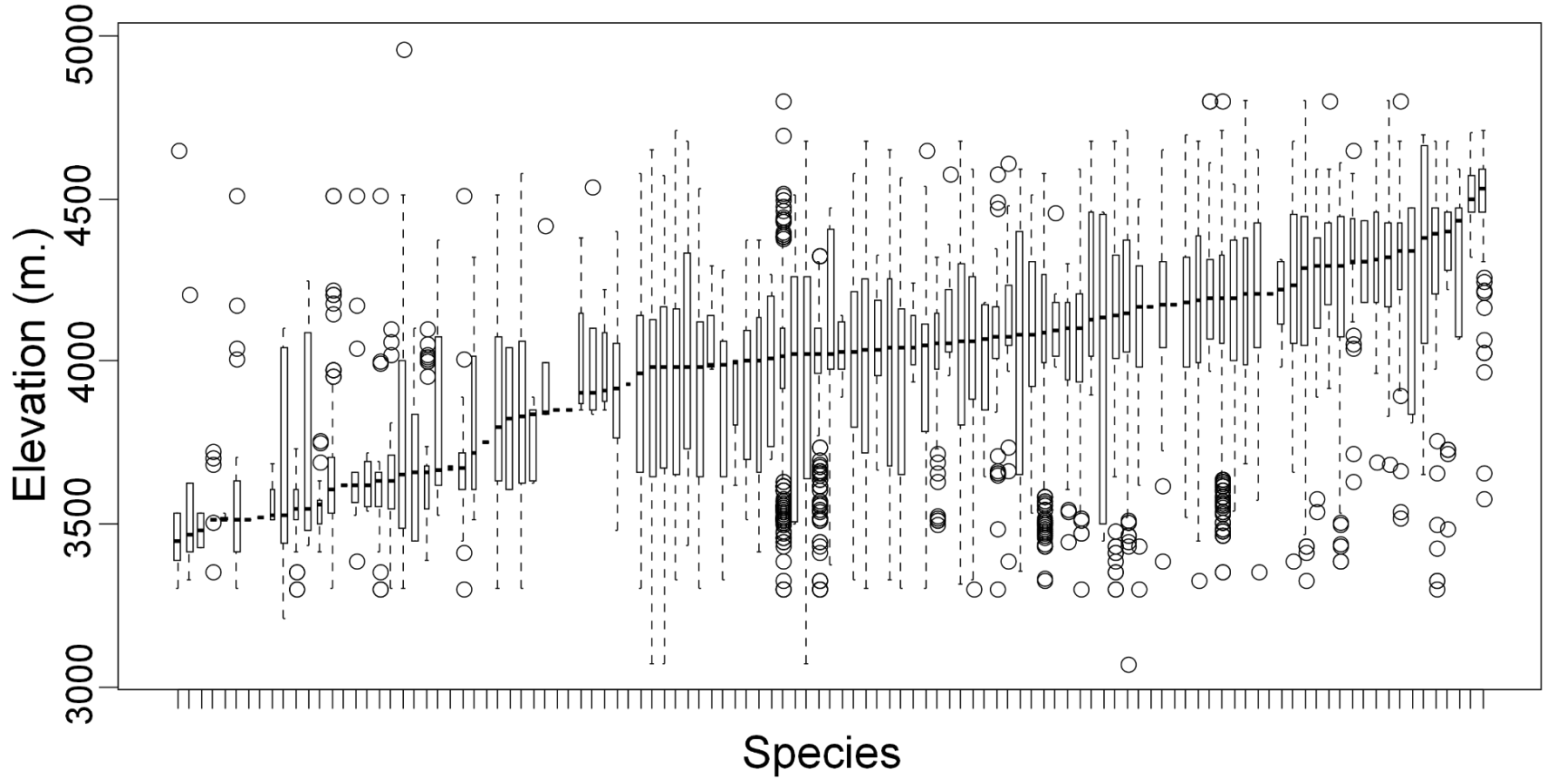


Fig. 19. Boxplot of species range distribution along elevation with 109 species ordered by their elevation median.



CHAPTER IV

AVIAN COMMUNITY STRUCTURE AND HABITAT USE ALONG AN ELEVATIONAL GRADIENT OF *POLYLEPIS* WOODLANDS

ABSTRACT

Polylepis forests of the Andes are among highest and most unique forest systems in the world, and as such, are recognized centers of endemism and diversity. Yet the forests continue to be threatened by human disturbance, fragmentation, and climate change, making it a system of high conservation concern. Effective conservation efforts are limited, in part, by our poor understanding of the flora and fauna associated with *Polylepis* and their habitat needs. In 2014-2015, I studied bird communities and associated local and landscape attributes in five forested glacial valleys in Huascaran National Park and Biosphere Reserve, Peru. Birds were surveyed in wet and dry seasons at 130 points distributed along an elevational gradient (3,300-4,700 m) in five glacial valleys. Avian survey data and 19 environmental variables also measured at each point were analyzed using a Canonical Correspondence Analysis (CCA). A total of 50 species of birds, including 13 species of conservation priority, were associated with four habitat types identified: (1) *Polylepis sericea* forests at low elevations, (2) *P. weberbaueri* forests at high elevations, (3) Puna and open habitats, and (4) shrubland. Four species of conservation priority (*Oreomanes fraseri, Poospiza alticola, Atlapetes rufigenis,* and *Cranioleuca baroni*) were strongly associated with structural characteristics of large forest patches (~10 ha) dominated by *P.sericea* at lower elevations (<3,800 m), whereas another four (*Anairetes alpinus, Leptasthenura yanacensis, Zaratornis stresemanii,* and *Scytalopus affinis*) were

associated with less disturbed forests of *P. weberbaueri* at upper elevations (> 4,200 m). Results suggest that, in addition to conserving and using large (>10 ha) *P. sericea* forests at lower elevations as the cornerstone for maintaining bird diversity, any high elevation (> 4,200 m) relicts of *P. weberbaueri*, irrespective of size, should be prioritized for conservation in order to protect key habitat of threatened species in Cordillera Blanca.

RESUMEN

Los bosques de *Polylepis* son reconocidos como centros de alta importancia para la conservación debida al gran número de aves endémicas y en peligro de extinción, que de ellos dependen. Este estudio, describe las asociaciones de la comunidad de aves del Parque Nacional Huscarán, Ancash Perú, a lo largo de una gradiente de elevación entre los 3,300- 4,700 m. La abundancia relativa de las aves fue evaluada durante las estaciones de lluvia y seca en 130 puntos distribuidos en 5 valles glaciares, donde 19 variables ambientales también fueron medidas para cada punto y analizados mediante un análisis de componentes canónicos (CCA). Un total de 50 especies de aves, incluyendo 13 especies de prioridad de conservación, se asociaron a cuatro tipos de hábitats identificados: (1) los bosques de *Polylepis sericea* a menores elevaciones, (2) bosques de *P. weberbaueri* a altas elevaciones, (3) Puna y hábitats abiertos, y (4) zonas arbustivas. Cuatro especies de prioridad de conservación (*Oreomanes fraseri*, *Poospiza alticola*, *Atlapetes rufigenis*, y *Cranioleuca baroni*) fueron altamente asociadas a las características estructurales de grandes parches de bosque (~ 10 ha) dominadas por *P.sericea* a elevaciones bajas (<3,800 m), mientras que otras cuatro especies (*Anairetes alpinus*, *Leptasthenura yanacensis*, *Zaratornis stresemanii*, y *Scytalopus affinis*) se asociaron con los bosques menos perturbadas de *P. weberbaueri* a mayores elevaciones (> 4.200 m). Los resultados sugieren que, además de conservar y usar los grandes bosques de *P. sericea* (> 10 ha) de bajas elevaciones como la piedra angular para el mantenimiento de la diversidad de aves, cualquier relictos de *P. weberbaueri* a mayores elevaciones (> 4.200 m),

independientemente de su tamaño, debe ser priorizada para la conservación con el fin de proteger el hábitat de las especies de aves mas amenazadas en la Cordillera Blanca.

INTRODUCTION

Tropical mountains are well known to support impressively high species diversity and endemism (Maselli *et al.,* 2010), and the Tropical Andes, in particular, stand out as a biodiversity hotspots (Myers *et al.,* 2000). One unique Andean system is the *Polylepis* forest. As one of the world's highest elevation forests (Gareca *et al.,* 2010), *Polylepis* forests also are a center of avian diversity (Fjeldså *et al.,* 1999; Fjeldså, 2002) and endemism (Young 2007; Fjeldså, 1993, Fjeldså *et al.,* 1999), with several birds restricted to that specific ecosystem (Gareca *et al.,* 2010; Fjeldså and Kessler, 2004; Lloyd, 2008a,b,c; Lloyd and Marsden, 2008). Unfortunately, *Polylepis* forests continue to be threatened by habitat loss, fragmentation, and degradation (IUCN, 2015; Birdlife Conservation, 2015) while facing future threats from climate change (Şekercioğlu *et al.,* 2012).

Although several studies have described bird communities associated with *Polylepis* woodlands (Fjeldså and Krabbe, 1990; Herzog *et al.,* 2002; Fjeldså and Kessler, 2004; Lloyd and Marsden, 2008; Lloyd, 2008a; Matthysen, 2008; Tinoco *et al.,* 2013), few have examined specific habitat associations of birds there (Lloyd and Marsden, 2008; Lloyd, 2008a; Tinoco *et al.,* 2013). Even fewer have systematically surveyed birds across the entire elevation gradient covered by the ecosystem (McCain, 2009). In terms of elevation, several *Polylepis* tree species are restricted to the highest parts of the Tropical Andes (3,500 m to 4,700 m), but elevational ranges vary widely, spanning from 900 m (Márcora, 2013) to 5,200 m (Troll, 1973; Simpson, 1979; Kessler, 2005). Recent studies have found that many *Polylepis* specialist birds are closely associated with the physical characteristics of the landscape (e.g., patch size,

connectivity) (Lloyd and Marsden, 2008; Tinoco *et al.*, 2013) and local habitat use (Lloyd, 2008c). Because local and landscape attributes likely change with elevation, a deeper understanding of bird-habitat association is an essential first step to guide conservation of several *Polylepis* endangered bird species.

As such, this study aimed at identifying habitat and landscape associations of some of the most threatened and endemic bird species along one of the highest elevation gradients of the central Andes – Cordillera Blanca in Peru.

METHODS

Study area

This research was conducted in Cordillera Blanca, the highest tropical mountain range in the world, located in Ancash Department in Peru (-9.336, -77.385). Study sites were located within Huascaran National Park and Huascaran Biosphere Reserve, both protected since 1975 and declared a world heritage site by UNESCO in 1985 (Plan Maestro PNH, 1990, 2002, 2010). The complex topography of the study area includes 44 deep glacial valleys spanning extensive elevational gradients that, in only a few kilometers, ascend from 2,400 m, to mountains reaching 5,000 m to 6,768 m, at the peak of Huascaran, the world's highest tropical mountain (Byers, 2000). Each valley included several patches of *Polylepis* forest surrounded by a matrix of bushes, grasslands, wetlands, lagoons and other plant communities (Fig. 20). These forests represent the largest extents of *Polylepis* woodland under protection in the world (Zutta, 2009; Zutta *et al.*, 2012). Mean annual rainfall is ~844 mm and is most plentiful at higher elevations (Schauwecker *et al.*, 2014). There is also a strong

seasonality, with the year partitioned into dry (May to August) and wet (September through April) seasons, with precipitation peaking during January through March (~130 mm per month). Mean annual temperature is 13.5 °C, but daily temperatures can plummet to -15°C at night and soar to 23 °C at noon during the dry season.

Five glacial valleys on the Pacific slope were surveyed, selected based on accessibility, elevational gradients, and spatial distribution along the Cordillera Blanca. Three parallel valleys ranging from 3,300 m to 4,700 m were located in the north of Cordillera Blanca (Parón, Llanganuco and Ulta), and two valleys (Llaca and Rajucolta) were located more centrally within the Cordillera, covering an elevational gradient from 3,800 m to 4,700 m. Data were collected during mid-May to mid-August 2014, corresponding to the dry season, and during mid-January to mid-April 2015, corresponding to the wet season.

Bird surveys

I used a robust sampling design for multiple species to survey the bird community (Kendall *et al.,* 1997; Jolly, 1965; Kendall, 2001). A total of 130 points were surveyed for 3 consecutive days during each of the dry and wet season. Each point was visited three times during the dry season by a single observer, and five times during the wet season by two observers. At each point, the observer recorded all birds seen or heard within 50 m over a 10 min period. Surveys were conducted from sunrise (~0500-0600 h) to ~1200 h, and the order of surveys was reversed each visit to avoid bias related to bird activity, time of day, and/or observer experience (Lloyd, 2008a,b). For each bird detection we recorded, time, species, number of individuals, linear

distance from the point count center, and habitat type. Individuals detected multiple times were only counted once.

Points were separated by >150 m and stratified by elevation so as to span the entire elevational gradient of each valley (3,300 m to 4,700 m). GPS coordinates and elevation (±10 m) were recorded at every point, and adjusted with Google Earth images in some cases, with 30 points each in the larger valleys of Parón, Llanganuco and Ulta and 20 points each in the smaller valleys of Llaca and Rajucolta. A total of 70 points were located inside woodlands dominated by *Polylepis* trees, 46 in areas dominated by shrubs and short-statured trees, such as *Gynoxys/Buddleja*, 6 within *Eucalyptus* forest, and 8 in Puna grassland (Fig. 20).

Habitat surveys

During each season, field teams measured 19 habitat and landscape variables within a circular plot with a 10-m radius (only one was measured in a 50-m radius), centered on each point and divided into four quadrants by the intersection of North-South and East-West axes at the plot center (Fig. 21). Percentage of mosses, grass, rocks and bare ground were estimated in each quadrant and later averaged for use in analysis. In addition, the height and diameter at breast height (DBH) of the nearest tree (woody vegetation with individual main stems >10 cm DBH) within each quadrant were measured and the tree was identified to the species level. When dealing with multi-stemmed trees, the average DBH of individual stems was used for analysis. Biomass was calculated using the allometric equation (Eq. 1) developed for *Polylepis* trees by Espinoza and Quispe after their study in HNP in 2005.

$$Biomass = 0.0694 * DBH^{2.35996} \quad \text{(Eq. 1)}$$

The total number of trees >10 cm DBH was counted by quadrant, as well as the number of shrubs (multi-stemmed woody vegetation ≤ 10 cm DBH; typically *Lupinus, Senecio, Berberis, Baccharis, Gynoxys* and small *Polylepis*) in order to estimate tree and shrub density in the circular plot. The total was adjusted for an area of 100 m^2. As an indicator of vertical forest structure, canopy depth, defined as canopy height minus the height of the canopy base, and groundcover height (groundcover: vegetation ≤ 50 cm) also were measured at each quadrant. We used the mean of these variables for the subsequent analysis. A spherical densiometer was used to estimate canopy cover at the center of every point. For the landscape measurements, I estimated the percentage of forest within a 50 m circular plot, the patch size of forest in ha (points outside forest were 0 ha), and the distance from the point center to the nearest forest edge (positive values indicated inside the forest and negative outside). All metrics were calculated using Quantum GIS Geographic Information System and the OpenLayers Plugin 1.3.6 based on CNES/Astrium satellite images from Google Earth 2015 with 1-m resolution.

Data analysis

Because habitat variables did not differ statistically between seasons, I used the mean of the two seasons in all analyses. Habitat variables were tested for normality and independence using Shapiro-Wilk W test ($p<0.01$) and Spearman's D correlation test ($r<0.75$), respectively. I compared habitat attributes among the 5 valleys using the

non-parametric Kruskal-Wallis test. Changes in habitat along the elevation gradient were examined using a non-metric multidimentional scaling (NMMS) and Bray-Curtis similarity index on Past 3.08 (Hammer, 2001).

Changes in forest composition (i.e., *Polylepis* spp.) with elevation were examined using an occupancy model with elevation as the single covariate in program MARK (White and Burnham, 1999). I used detection/no-detection data for both *Polylepis* species at each point count with a detection probability equal to one (p =1). Bird-habitat associations were examined using a canonical correspondence analysis (CCA) (Braak, 1986; Lloyd, 2008c), which illustrates relationships in a biplot of the two vectors with the highest eigenvalues (Braak, 1986). The analysis was restricted to those 50 bird species that were observed at least 20 times over both seasons and over the 130 point count locations. These species included 6 bird species identified as Peruvian endemics and 6 listed on the International IUCN Red List of threatened species (Birdlife Conservancy, 2015) (Table 5).

RESULTS

Habitat characteristics

Both the NMMS and occupancy models showed that habitat changed with elevation (Table 6, 7 & 8 and Fig. 22). Specifically, elevation was a significant predictor of occupancy for both *Polylepis* species (Likelihood ratio test: *P. sericea*: x^2=18.58, df=1, p=0.0001; *P. weberbaueri*: x^2=36.98, df=1, p=0.0001) (Table 8); with *P. sericea* being replaced by *P. weberbaueri* as elevation increased (Fig. 23). The occupancy estimates that 33% of the study area was occupied by *P. sericea* (Psi-hat:

0.33; SE: 0.044; 95% CI: 0.25-0.43) and 17% for *P. weberbaueri* (Psi-hat: 0.17; SE: 0.042; 95% CI: 0.10-0.27). Occupancy probability for *P. sericea* decreased monotonically with increasing elevation, from 0.8 at 3,300 m, 0.5 at 3,870 m and only 0.1 at 4,680 m; whereas *P. weberbaueri* increased more rapidly from 0.1 at 3980 m, to 0.5 at 4,390 m and to 0.8 at 4,680 (Fig. 23). A coexistence zone between 4,060 to 4,350 m was predicted by models and corroborated by observations (Fig. 24).

For other habitat variables, the first NMMS axis was positively associated with elevation, DBH, *P. weberbaueri,* and biomass and it was negatively associated with groundcover height and shrub density (Table 7 and Fig. 22). The second NMMS axis was negatively associated with elevation and positively associated with structural characteristics, mainly of *P. sericea* forest (e.g., tree height, canopy cover, canopy depth), and landscape characteristics, including amount of forest, patch size and internal distance to the edge. Collectively these axes showed that sampled forest landscapes in lower elevations were characterized by large patches (~>10 ha) dominated by *P. sericea,* with smaller trees than upper elevations, lower biomass, and greater numbers of trees and shrubs. Sampling points at higher elevations, on the other hand, were dominated by smaller patches of *P. weberbaueri* with forests that had taller and larger trees, high canopy cover, and comparatively less understory height.

Habitat and bird community ordination

The first two CCA vectors accounted for 48.3% of the variation in abundance of 50 bird species with respect to the 19 measured habitat variables, with a sum of all eigenvalues of 0.74. The first vector explained 28.7% of the variation and showed a strong association with low elevations, large patches of *P. sericea,* high tree densities,

dense canopy cover, and height of understory vegetation. The second vector explained 19.6% of the variance and was positively associated with small patches of *P. weberbaueri* at high elevation and with tall trees, high canopy cover, abundant mosses, and low amounts of grass and shrubs (Table 9 & Fig. 25).

Birds were associated with four main clusters of habitat attributes (Fig. 26): (1) habitat structure associated with *P. sericea* dominated forest (e.g., canopy cover, patch size, forest interior (distance to the edge), tree density and height) (Cluster I), (2) habitat structure associated with *P. weberbaueri*, such as higher levels of mosses, rocks, biomass, DBH and slope (Cluster II), (3) grassland associated with Puna or other open habitats (Cluster III), and (4) dense areas with tall herbaceous groundcover and high shrub density (Cluster IV).

Seventeen bird species were strongly associated with *Polylepis* forest. Of these, 9 species were associated with *P. sericea* habitat (Cluster I), including four threatened/endemic species: the Rufous-Eared Brush-Finch (*Atlapetes rufigenis*), Plain-tailed Warbling-finch (*Poospiza alticola*), Giant Conebill (*Oreomanes fraseri)* and the Baron's Spinetail *(Cranioleuca antisiensis baroni*)*;* three widely distributed insectivores: Black-crested Warbler (*Myiothlypis nigrocristata*); Rufous-Breasted Chat-tyrant (*Ochtoeca rufipectoralis*), Brown-Bellied Swallow (*Notiochelidon murina*) and two hummingbirds: Shining Sunbeam (*Aglaeactis cupripennis*) and Tyrian Metaltail (*Metallura tyrianthina*). The other eight species were associated with *P. weberbaueri* habitat (Cluster II). These included the endangered Ash-breasted Tit-tyrant (*Anairetes alpinus*), the near-threatened Tawny Tit-spinetail (*Leptasthenura yanacensis*), the endemic and vulnerable White-cheeked Cotinga (*Zaratornis*

stresemanii), the endemic Ancash Tapaculo (*Scytalopus affinis*), and the widespread Stripe-headed Antpitta (*Grallaria andicolus*), White-Throated Tyrannulet (*Mecocerculus leucophrys*), Thick-Billed Siskin (*Spinus crassirostris*), and Tit-like Dacnis (*Xenodacnis parina*) (Table 10).

Interestingly, many species were associated with grasslands and shrublands (Cluster III and IV). Seventeen species were associated with grasslands and open habitats (e.g., flycatchers, canasteros, finches, ground-tyrants, earth creepers, and hummingbirds), although only one of these was an endemic species - Striated Earthcreeper (*Geocerthia serrana*). Another sixteen species were associated with shrublands (Cluster IV), including two endemic species - Black Metaltail Hummingbird (*Metallura phoebe*) and Rusty-Crowned Tit-Spinetail (*Leptasthenura pileata*).

DISCUSSION

Polylepis woodlands in Huascaran National Park and Biosphere supported unique bird communities, including several threatened and endemic bird species (Fjeldså and Kessler, 2004; Gareca *et al.,* 2010). Bird communities changed markedly along elevational gradients in response to shifts in habitat structure and floristics within each of the valleys. Birds generally were associated with four types of habitat within the valleys – (1) lower elevation *P. sericea* forests, (2) higher elevation *P. weberbaueri* forests, (3) grasslands and Puna habitat, and (4) successional shrublands. Although each of these habitats supported at least one endemic or declining species, the *Polylepis* woodlands supported the greatest number of threatened and endemics.

However, individual species were associated with different characteristics of each of the two types of *Polylepis* habitat defined here.

At lower elevations (3,300 – 4,000 m); four birds of concern were strongly associated with large patches of mature *P. sericea* forests. These include the near-threatened Giant Conebill (*Oreomanes fraseri*), a bird that specializes in nesting (Cahill *et al.,* 2008) and foraging on *Polylepis* bark (Fjeldså and Krabbe, 1990; Lloyd, 2008b, Servat, 2006), that in our analysis was mainly associated with the interior of the forest and large diameter trees. My finding is consistent with previous studies showing that the Giant Conebill favored large trees in mature forests (Lloyd, 2008a) and avoided edges (Cahill and Matthysen, 2007). The other three species, the Plain-tailed Warbling-finch (*Poospiza alticola*), the Banon's Spinetail (*Cranioleuca baroni*) and the Rufous-eared Brush-finch (*Atlapetes rufigenis*), are recognized as endemics but otherwise their ecology is poorly known (Huffstater, 2012; Jaramillo, 2011; Schulenberg and Jaramillo, 2015). In my system, the Plain-tailed Warbling-finch and the Banon's Spinetail were associated with the interior of large patches of dense and mature *Polylepis* forest at relatively much lower elevations than the Giant Conebill. Rufous-eared Brush-finch, on the other hand, seemed better able to persist on smaller patches and near edges. The Plain-tailed Warbling-Finch, which is listed as endangered (EN) by Birdlife International, was relatively common in my study area and was often seen foraging in pairs, familiar groups and/or mixed flocks in *Polylepis sericea* mixed forest with *Gynoxys* and *Alnus*, (Steven Sevillano. Per Obs.). Further population studies are needed to better understand its status and the extent to which my observations might signal population recovery. Three other species widely

distributed along the Andes, the Rufous-breasted Chat-tyrant (*Ochthoeca rufipectoralis*), the Black-crested Warbler (*Myiothlypis nigrocristata*) and the Shining Sunbeam (*Aglaeactis cupripennis*) were associated with the interior of *P. sericea* forest.

At upper elevations (>4, 000 m), some of the most endangered species were associated with what are likely less disturbed *P. weberbaueri* forests (more natural or pristine) based on their remoteness, inaccessibility, in very steep and rocky terrain with high abundance of mosses. Included among these species was one of most highly threatened species of the Andes, the Ash-breasted Tit-tyrant (*Anairetes alpinus*), which has a very small global population of 780 individuals that declined by 10% - 19% from 2002-2012 in Peru and Bolivia (50 CFR Part 17, U.S. Fish and Wildlife Service, 2012). Another two birds of concern, the endemic and vulnerable White-cheeked Cotinga (*Zaratornis stresemanii)* and the neared threatened Tawny Tit-spinetail (*Leptasthenura yanacensis*), were also *Polylepis* specialists and were strongly associated with mosses and rocks inside remote *P. weberbaueri* stands, suggesting that they require more natural or pristine characteristics found in the less accessible high elevations, regardless of patch size. These findings are consistent with studies in Cuzco, Peru (Lloyd, 2008b), Bolivia (Cahill and Matthysen, 2007) and range-wide descriptions made by Fjeldså and Krabbe (1990), who also describe high variability in edge-avoidance by the Tawny Tit-spinetail.

Thus, conservation of high-elevation patches, regardless of size, will likely prove essential to maintaining populations of these threatened species. Previous studies of *Polylepis* forest in Cordillera Blanca registered none or very few Ash-

breasted Tit-tyrants, despite covering a large number and area of *Polylepis* woodlands (Sevillano *et al.*, 2011; Frimer and Nielsen, 1989; Fjedsa, 1987). However, these studies mainly examined forest below 4300 m. This suggests that even large *Polylepis* forests at low elevations will not be sufficient to maintain populations of some threatened species like the Ash-breasted Tit-tyrant. Therefore, the conservation of high elevation *Polylepis* patches, regardless of their size would be a priority for the conservation of these bird species.

A surprising number of birds were associated with Puna grasslands and shrublands. Although these environments are typically considered hostile (Lloyd and Marsden, 2008), they were heavily used by several hummingbirds, including the endemic *Metallura phoebe,* tyrants, flycatchers, canasteros and finches. One possible explanation for the relatively high diversity in grasslands and shrublands is that they offer a higher diversity of resources that complement those available in *Polylepis* woodlands. A recent study suggested that *Gynoxys*, a common woody tree/shrub that occurs within several *Polylepis* forests along the Andes, plays an important role in the composition and structure of the *Polylepis* bird community in Ecuador (Tinoco *et al.,* 2014). Not only does *Gynoxys* produce sugary secretions and host a high variety of arthropods, it also provides structure that improves connectivity among *Polylepis* patches (Fjeldså and Krabbe, 1990; Kessler, 2006). Importantly, my field observations suggest that the value of open habitats may depend, in part, on the proximity to *Polylepis* forest, because I observed many of the grassland/shrubland-associated birds roosting in forests at night, when air temperatures drop to freezing in open areas, but remain warmer inside the forest (Per. Com. L.V.Morales, 2015). From a conservation

perspective, then, *Polylepis* forest may support the broader bird community in the valleys and not only *Polylepis* specialists.

One unexpected finding of my study was the floristic shift along the elevational gradient, whereby larger patches of the shorter *P. sericea* forests (typically below 3,800 m) were gradually replaced by smaller patches of larger and taller *P. weberbaueri* trees at higher elevations. The greater height and larger DBH of *Polylepis* trees at upper elevations (Fig. 24) is counter-intuitive, given the harsh environment, but could result from lower levels of human activity and resource extraction at the higher and more inaccessible areas. Kessler *et al.*, (2014), found a marginally significant relationship between tree height and human disturbance, across a range of *Polylepis* species in disturbed areas, being marginally smaller than those in undisturbed areas in Cusco. For this reason, high elevation remnants in inaccessible areas may be the only remaining examples of the more "natural" vegetation conditions of *Polylepis* forest, similarly to what was suggested for other plants communities in Cuzco (Sylvester *et al.*, 2014). However, another explanation could be simply differences in the climatic niche optima between species and their different physiological/genetic characteristics. The replacement pattern of *Polylepis sericea* with P. weberbaueri at higher elevations suggests that the species have different tolerances (e.g., physical, edaphic, climatic and ecological), which has important implications for the growing number of *Polylepis* reforestation, afforestation and general restoration projects. For example, many projects may not select the most suitable species, but instead often elect to use other *Polylepis* species (e.g., *P. incana* and *P. racemosa*) that respond well initially but suffer high mortality after 15-20 years

(Per Com. C. Aucca-ECOAN), and may even compete with native species (CONDESAN, 2011).

My research has three implications for conservation: 1) large patches (~10 ha) of mature *Polylepis* at low elevations should be a cornerstone for Andean bird conservation; 2) small *Polylepis* patches at high elevations provide unique habitat to severely threatened species and, thus, are critical refuges that also warrant protection; and 3) habitats that are usually less recognized for their conservation value, such as grasslands and shrublands, support large numbers of species, including some endemics. However, the degree to which the suitability of those habitats is related to proximity of *Polylepis* forest for roosting warrants further study. An important caveat to my findings is that I focused on habitat use and associations and, therefore, cannot speak to the quality of the habitat nor the extent to which birds survived and successfully reproduced. Given the paucity of information on survival and reproduction of birds using *Polylepis* forest, much additional work is required to evaluate habitat quality and to identify the key habitat features required to support populations.

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TABLES

Table 5. Species of conservation concern in Huascaran National Park and Biosphere – Ancash, Peru. The degree of *Polylepis* specialization is based on Lloyd 2008 and Fjeldså 2002. Endemism is in reference to Peru. Data: Birdlife Conservancy. * Insufficient data for the CCA analysis. E: Endemic

Species	Common Name	*Polylepis* specialist	E	IUCN	Family	Population size (mature individuals)	Population trend	Distribution size (breeding/resident)
Poospiza alticola	Plain-tailed Warbling-finch	High	Yes	EN	Emberizidae (Buntings, American sparrows and allies)	600-1700	Decreasing	9,900 km2
Anairetes alpinus	Ash-breasted Tit-tyrant	High	No	EN	Tyrannidae (Tyrant-flycatchers)	150-700	Decreasing	11,900 km2
Zaratornis stresemanni	White-cheeked Cotinga	High	Yes	VU	Cotingidae (Cotingas)	1000-4000	Decreasing	77,300 km2
Oreomanes fraseri	Giant Conebill	High	No	NT	Thraupidae (Tanagers)	Unknown	Decreasing	232,000 km2
Leptasthenura yanacensis	Tawny Tit-spinetail	High	No	NT	Furnariidae (Ovenbirds)	Unknown	Decreasing	74,200 km2
Atlapetes rufigenis	Rufous-eared Brush-finch	High	Yes	NT	Emberizidae (Buntings, American sparrows and allies)	Unknown	Decreasing	21,300 km2
**Megascops koepckeae*	Koepcke's Screech Owl	Middle	Yes	LC	Strigidae (Typical Owls)	Unknown	No data	190 000 km2
Geocerthia serrana	Striated Earthcreeper	Low	Yes	LC	Furnariidae (Ovenbirds)	Unknown	Decreasing	96,800 Km2
Leptasthenura pileata	Rusty Crowned Tit-Spinetail	Middle	Yes	LC	Furnariidae (Ovenbirds)	Unknown	Stable	93,200 km2
Scytalopus affinis	Ancash Tapaculo	High	Yes	LC	Rhinocryptidae (Tapaculos)	Unknown	Stable	15,400 km2
**Incaspiza personata*	Rufous Backed Inca-Finch	Low	Yes	LC	Emberizidae (Buntings, American sparrows and allies)	Unknown	Stable	30,600 km2

Table 6. Across-site differences for habitat variables (Mean ± SD) (Min - Max) and Kruskal-Wallis test at five glacial valleys in Huascaran National Park. Number of survey points (n=30 or 20) are indicated next to site names. Numbers of trees measured are indicated below tree height and dbh. Statistical differences are in bold ($p<0.05$).

	Total (n:130)	Llanganuco (n=30)	Llaca (n=20)	Ulta (n=30)	Rajucolta (n=20)	Parón (n=30)	Between-localities differences
Elevation (m)	**4080 ± 327.80 (3302 - 4678 m)**	**3999.33 ± 322.6 (3468 - 4513 m)**	**4274.7 ± 225.12 (4007 - 4610 m)**	**4030.13 ± 331.9 (3515 - 4495 m)**	**4249.3 ± 240.4 (3965 - 4678 m)**	**3971.67 ± 67 (3302 - 4591 m)**	**X^2:14.96, p<0.005**
DBH (cm)	29.73 ± 33.84 (10 - 253 cm) (n=274)	28.91 ± 26.87 (10 - 158 cm) (n=69)	28.52 ± 22.52 (10 - 117 cm) (n=49)	23.40 ± 34.86 (10 - 253 cm) (n=53)	41.22 ± 33.91 (10 - 132 cm) (n=33)	30.78 ± 43.82 (10 - 219 cm) (n=70)	X^2:6.117, p=0.191
Tree height (m)	6.35 ± 2.96 (1.5 - 20 m) (n=274)	6.19 ± 2.58 (1.5 - 14 m) (n=69)	5.21 ± 2.84 (1.8 - 11 m) (n=49)	8.57 ± 3.97 (1.6 - 20 m) (n=53)	7.02 ± 2.30 (3 - 16 m) (n=33)	5.32 ± 1.72 (2 - 10 m) (n=70)	X^2:1.436, p=0.838
Groundcover height (m)	**0.84 ± 0.34 (0.00 - 1.68 cm)**	**1.00 ± 0.35 (0.4 - 1.68 cm)**	**0.77 ± 0.22 (0.45 - 1.25 cm)**	**0.77 ± 0.42 (0.00 - 1.63 cm)**	**0.65 ± 0.19 (0.23 - 1.03 cm)**	**0.94 ± 0.27 (0.58 - 1.38 cm)**	**X^2:21.166, p=0.001**
Canopy depth (m)	1.4 ± 1.42 (0.00 - 11 m)	1.45 ± 1.12 (0.00 - 4.33 m)	1.27 ± 0.79 (0.00 - 2.63 m)	1.81 ± 2.39 (0.00 - 11 m)	0.99 ± 1.04 (0.00 - 3.5 m)	1.32 ± 0.77 (0.00 - 2.75 m)	X^2:2.566, p=6.33
Tree Density (Ind/100 m^2)	3.15 ± 3.82 (0.00 - 17.19)	4.45 ± 4.96	4.04 ± 6.13	2.76 ± 3.83	2.56 ± 3.57	2.36 ± 2.22	X^2:4.699, p=0.320
Bushes Density (Ind/100 m^2)	14.47 ± 12.08 (0.00 - 111.41)	24.09 ± 13.18	10.15 ± 6.03	17.46 ± 14.69	9.60 ± 7.63	10.47 ± 7.21	X^2:8.583, p=0.072
Moss cover %	**0.29 ± 0.25 (0.00 - 0.94)**	**0.31 ± 0.29**	**0.59 ± 0.25**	**0.22 ± 0.21**	**0.24 ± 0.18**	**0.19± 0.15**	**X^2:24.48, p=0.001**
Grass cover %	**0.27 ± 0.32 (0.00 - 0.95)**	**0.42 ± 0.32**	**0.21 ± 0.33**	**0.36 ± 0.31**	**0.32 ± 0.37**	**0.05 ± 0.14**	**X^2:29.88, p=0.001**
Rock cover %	**0.39 ± 0.26 (0.00 - 0.95)**	**0.28 ± 0.21**	**0.71 ± 0.22**	**0.32 ± 0.22**	**0.32 ± 0.37**	**0.30 ± 0.18**	**X^2:38.75, p=0.001**
Bare ground cover %	**0.39 ± 0.26 (0.00 - 0.95)**	**0.11 ± 0.18**	**0.01 ± 0.02**	**0.06 ± 0.10**	**0.05 ± 0.06**	**0.06 ± 0.10**	**X^2:9.941, p=0.041**

Canopy cover %	0.50 ± 0.38 (0.00 - 1.00)	0.53 ± 0.40	0.56 ± 0.39	0.49 ± 0.44	0.41 ± 0.34	0.49 ± 0.41	X^2:1.113, p=0.892
Slope	23.24 ± 9.89 (5 - 48)	18.70 ± 9.17	25.2 ± 10.8	23.8 ± 11.0	24.6 ± 8.3	25.03 ± 8.9	X^2:8.18, p=0.085
Forest on 50 m-r plot (0.79 ha)	**0.35 ± 0.26 (0 - 0.79)**	**0.39 ± 0.26 (0 - 0.79)**	**0.47 ± 0.23 (0 - 0.79)**	**0.24 ± 0.25 (0 - 0.79)**	**0.27 ± 0.27 (0 - 0.79)**	**0.39 ± 0.25 (0 - 0.79)**	**X^2:13.529, p=0.009**
Patch size (ha)	**31.27 ± 50.68 (0 - 180.48)**	**62.35 ± 85.02 (0 - 180.48)**	**31.86 ± 29.94 (0 - 61)**	**3.94 ± 7.03 (0 - 20.7)**	**39.40 ± 43.19 (0 - 85.9)**	**21.68 ± 20.65 (0 - 44.3)**	**X^2:13.946, p=0.007**
Distance to the edge (m)	**-41.51 ± 186.56 (-1372 - 177)**	**-7.05 ± 72.79 (- 315 - 84)**	**31.67 ± 78.83 (- 165 - 177)**	**-60.2 ± 111.05 (- 414 - 60)**	**-192.8 ± 403.29 (- 1372 - 50)**	**-5.22 ± 64.31 (- 246 - 67)**	**X^2:16.235, p=0.003**

Table 7. Axis scores based on Non-Metric Multidimensional Scaling (NMMS) based on 19 habitat variables. Score values greater than 0.5 are in bold.

Habitat variables	Axis 1	Axis 2
Elevation (m)	**0.613**	**-0.504**
Slope	0.067	-0.056
%Mosses	0.226	0.174
%Grass	-0.236	-0.220
%Rocks	0.144	-0.029
%Bare ground	0.042	0.007
DBH (cm)	**0.717**	0.352
Tree height (m)	0.282	0.477
Groundcover height (cm)	-0.326	0.134
P. sericea **(Presence)**	-0.067	0.439
P. weberbaueri **(Presence)**	0.475	-0.103
Tree density (D. per 100 m^2)	0.037	0.361
Shrub density (D. per 100 m^2)	-0.240	0.098
Canopy covers	0.144	**0.504**
Canopy width (m)	0.182	0.450
Biomass	**0.834**	-0.010
%Forest on 50 m-r plot	0.075	**0.528**
Patch size (ha)	-0.162	**0.521**
Distance to the edge (m)	0.187	**0.553**

Table 8. Occupancy estimates (Psi) of *Polylepis sericea* and *P. weberbaweri* within Huascaran National Park. *p*=encounter probability and Elev = Elevation in m.

P. sericea	*Psi* - hat	SE	95% CI	AICc
p(1) Psi (Elev)	0.335	0.045	0.25 – 0.43	154.5
p(.) Psi (Elev)	0.335	0.045	0.25 – 0.43	154.5
p(.) Psi (.)	0.354	0.041	0.27 – 0.44	170.98
P. weberbaueri				
p(1) Psi (Elev)	0.168	0.043	0.10 – 0.27	116.52
p(.) Psi (Elev)	0.168	0.043	0.10 – 0.27	116.52
p(.) Psi (.)	0.262	0.039	0.19 – 0.34	149.41

Table 9. Ordination of 19 habitat variables on the first four canonical factors from the CANOCO analysis.

	Factor 1	Factor 2	Factor 3	Factor 4
Patch size (ha)	**0.536**	0.273	-0.040	0.051
P. sericea (presence)	**0.459**	-0.010	**0.249**	0.184
%Forest in 50 m-r plot	**0.429**	**0.514**	**0.262**	-0.119
Tree density	**0.356**	**0.316**	**0.211**	-0.106
Groundcover height (m)	**0.354**	-0.172	0.073	-0.138
Canopy depth (m)	**0.319**	**0.423**	0.137	**-0.217**
Canopy cover	**0.318**	**0.439**	0.156	**-0.216**
Tree height (m)	0.289	**0.435**	0.109	**-0.200**
Shrub density	0.162	-0.248	0.034	-0.108
Distance to the edge (m)	0.158	**0.443**	**0.317**	-0.019
DBH (cm)	-0.001	**0.381**	0.090	-0.022
Slope	-0.026	0.287	-0.125	-0.068
%Moss	-0.081	**0.522**	**0.230**	**-0.208**
%Grass	-0.082	**-0.431**	**-0.242**	**-0.334**
%Bare ground	-0.120	-0.002	**0.228**	0.103
Biomass	-0.158	0.189	0.076	0.022
%Rocks	-0.284	**0.392**	-0.082	-0.036
P. weberbaueri (presence)	-0.302	**0.601**	-0.033	-0.103
Elevation (m)	**-0.848**	**0.473**	0.095	0.173

Table 10. Ordination of the 13 species of concern for the first four canonical factors from the CCA. Higher values are shown in bold.

	Axis 1	Axis 2	Axis 3	Axis 4
Anairetes alpinus (EN)φ	**-1.310**	**3.243**	**-2.454**	0.970
Atlapetes rufigenis (NT) [E]	0.208	0.612	**1.003**	**-0.802**
Cranioleuca baroni [E]	0.877	**1.054**	0.923	0.256
Grallaria andiculus φ	-0.521	0.276	0.518	0.354
Leptasthenura pileta[E]	**1.109**	-0.709	0.151	**1.768**
Leptasthenura yanacensis (NT) φ	**-2.130**	**2.734**	**-2.341**	0.206
Metallura phoebe [E]	0.880	-0.499	0.447	0.355
Oreomanes fraseri (NT) φ	0.332	**1.571**	-0.090	**1.142**
Poospiza alticola (EN) [E] φ	**1.790**	0.843	0.408	0.279
Scitalophus affinis [E] φ	-0.525	0.518	0.232	0.777
Geocerthia serrana[E]	-0.947	-0.364	-0.455	**-0.999**
Xenodacnis parina φ	-0.327	0.408	0.584	**-0.752**
Zaratornis stresemanii (VU) [E] φ	-0.218	**2.608**	**-3.645**	**1.363**

φ=*Polylepis* specialist; [E] = Endemic

FIGURES

Fig. 20. Vegetation communities located along an elevational gradient including *Eucalyptus* forest usually at lower elevations (a), shrub areas dominated by *Gynoxys/ Budleja/ Baccharis/ Lupinus* species (b-c), Puna grassland areas dominated by *Stipa ichu* (d) and *Polylepis* woodland at lower (e) and upper elevation (f).
Photos: Steven Sevillano.

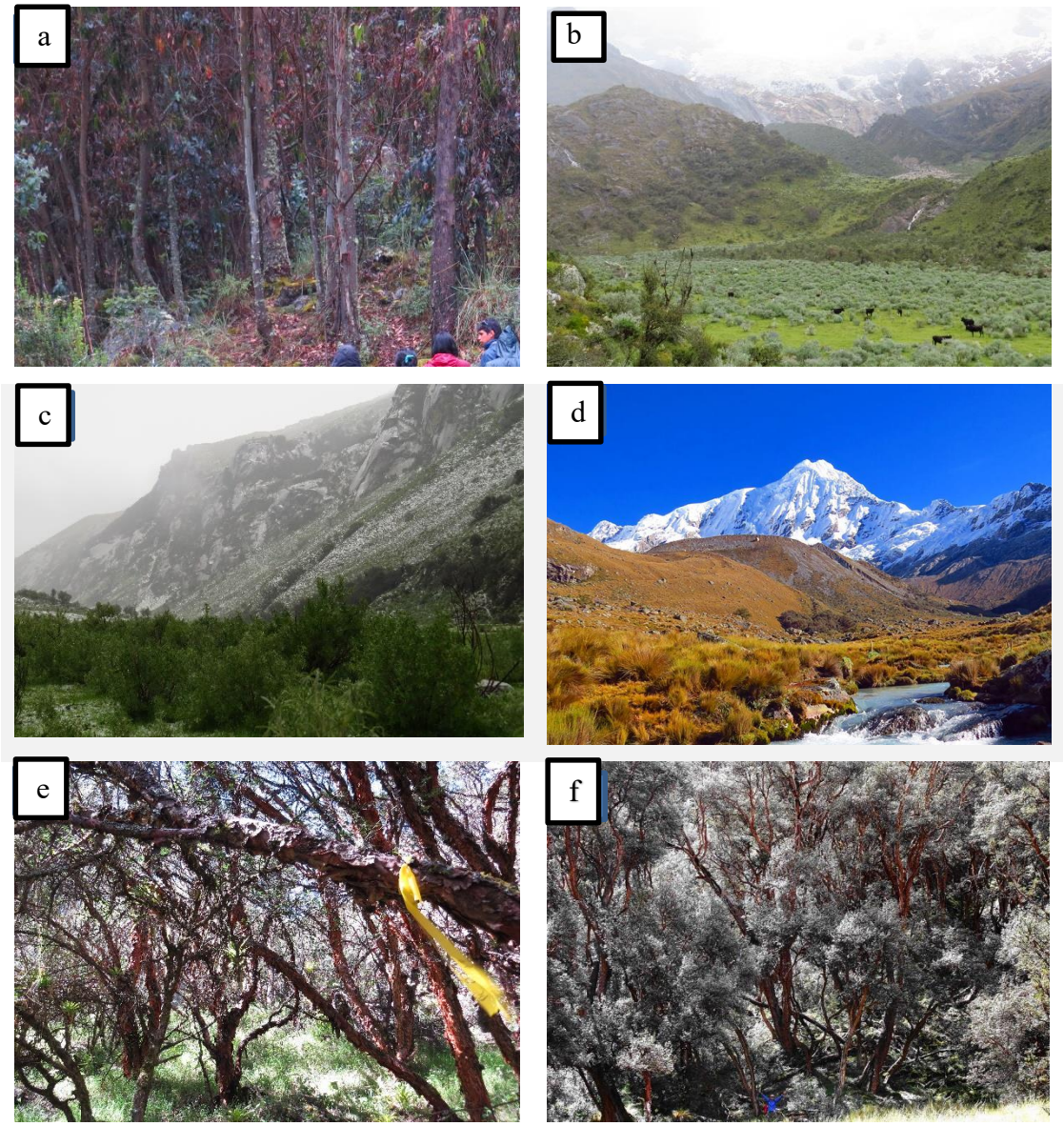


Fig. 21. Diagram of the 10 m and 50 m circular plot where selected environmental attributes were measured. Bird surveys were conducted from the center point of the plot.

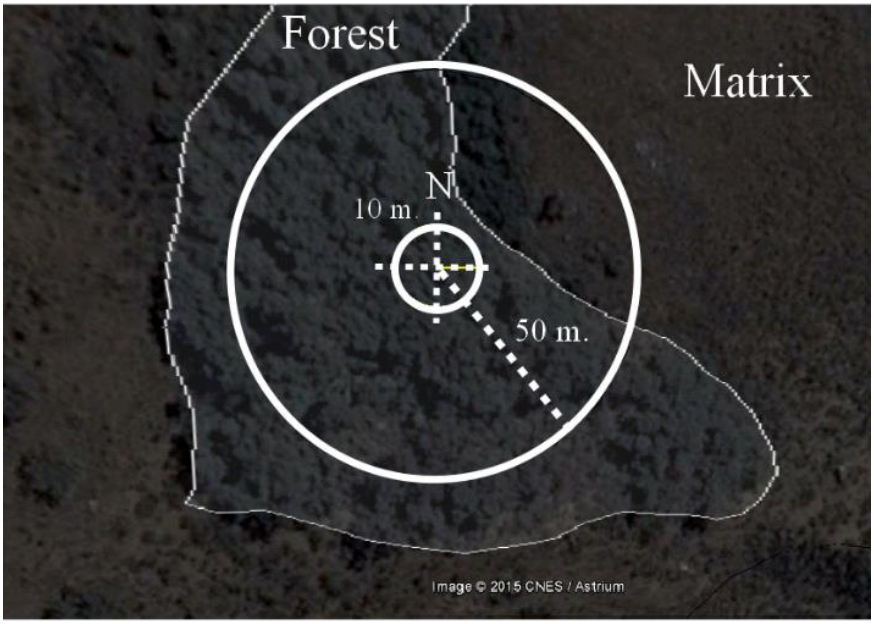


Fig. 22. Non-Metric Multidimensional Scaling (NMMS) ordinations of 130 points based on 19 habitat and physical characteristics along a 2-dimensional axis (coordinates). For visualization purposes, dot points represent locations below 3,800 m, cross points between 3,800 to 4,200 and square points over 4,200 m in elevation.

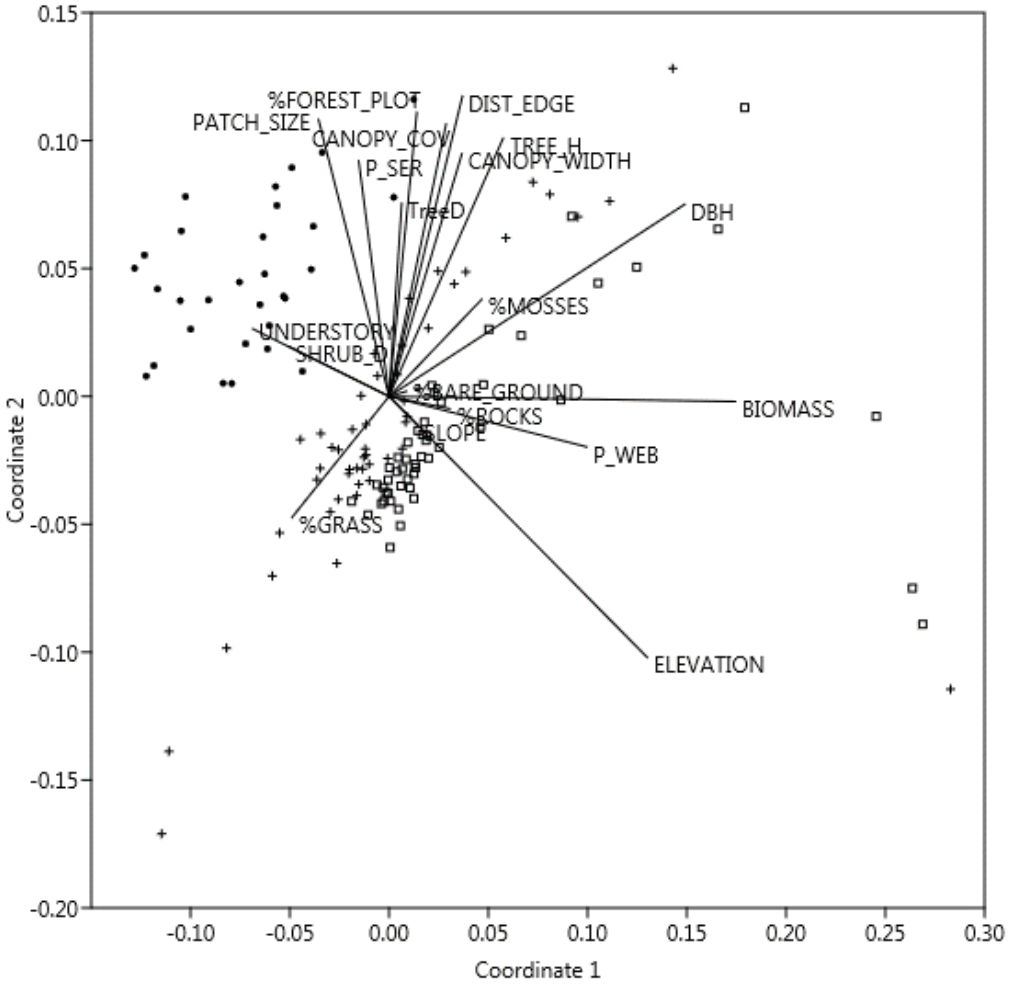


Fig. 23. Occupancy estimates (Ψ) for *P.sericea* and *P. weberbaueri* along an elevational gradient. Fine lines represent the 95% CI.

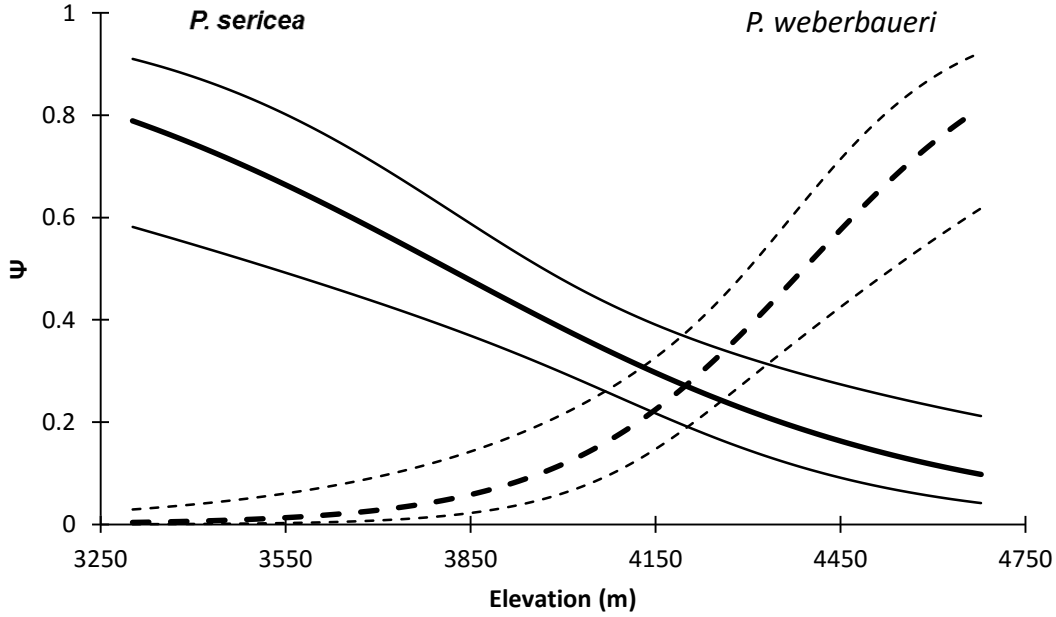


Fig. 24. Tree height and DBH (circle size) of *Polylepis sericea* (red) and *P. weberbaueri* (black) trees measured at 130 points along an elevational gradient.

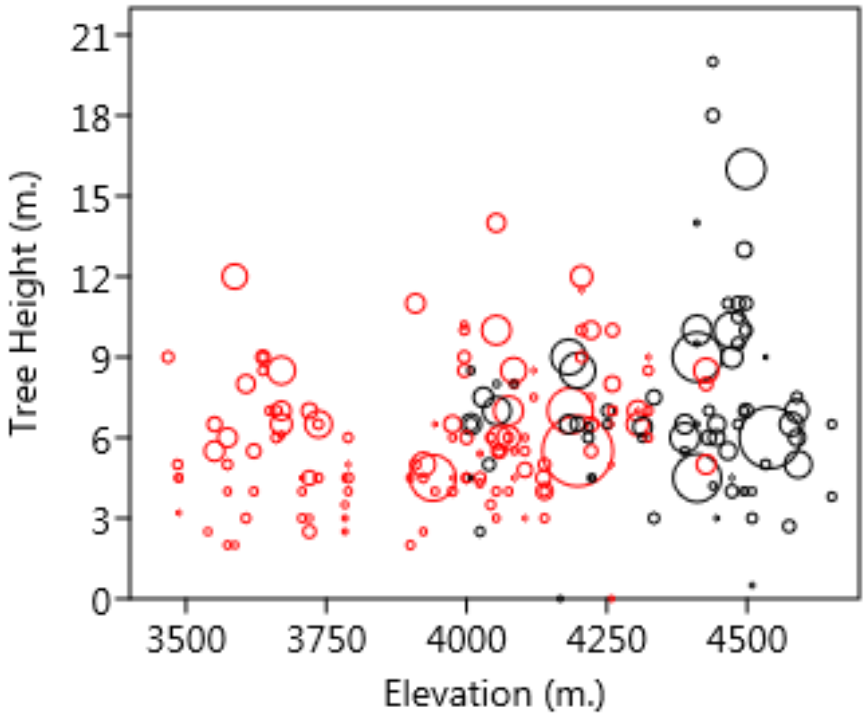


Fig. 25. Ordination plot of 19 habitat variables across an elevational gradient of *Polylepis* woodlands along the first two canonical axes from the CANOCO analysis.

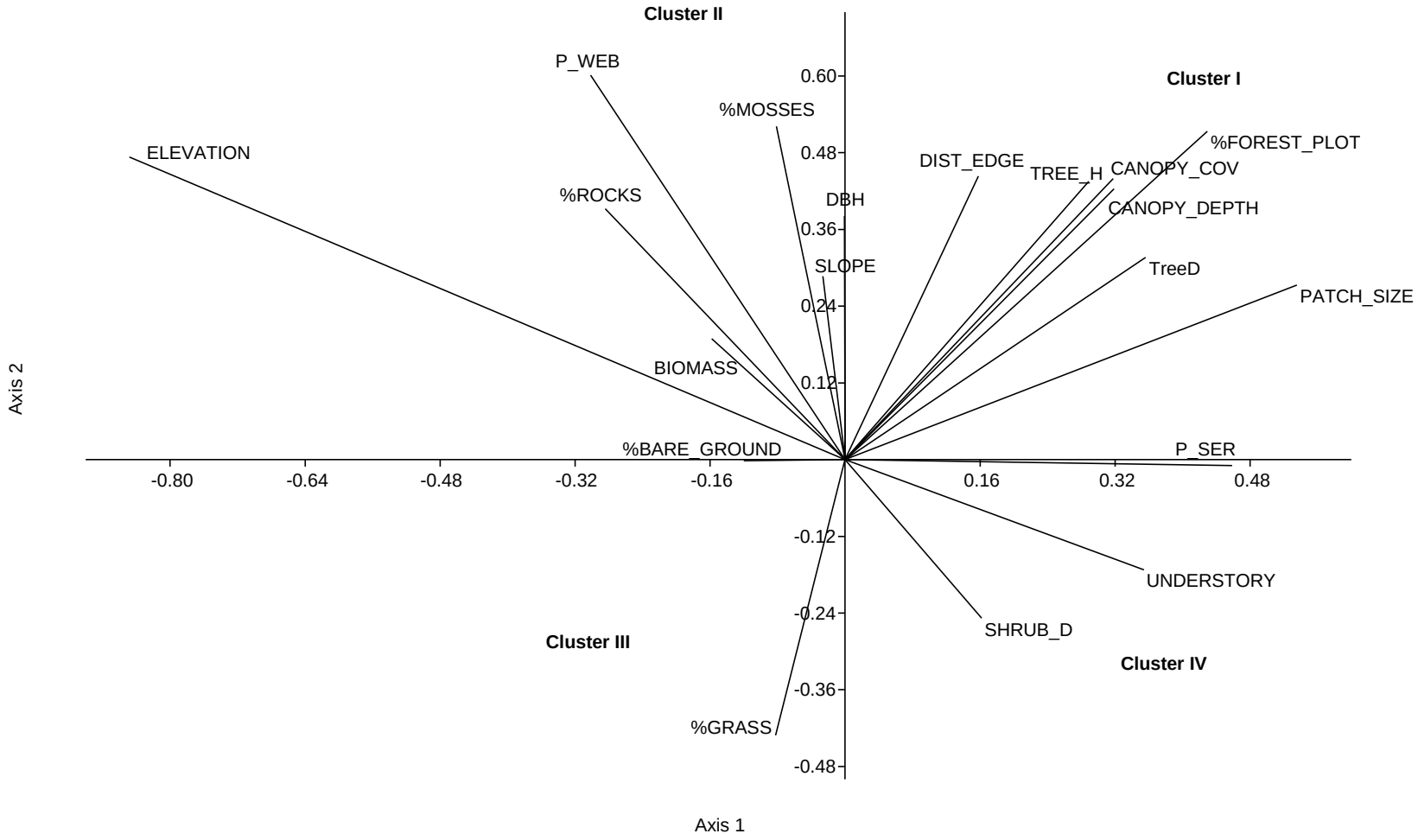
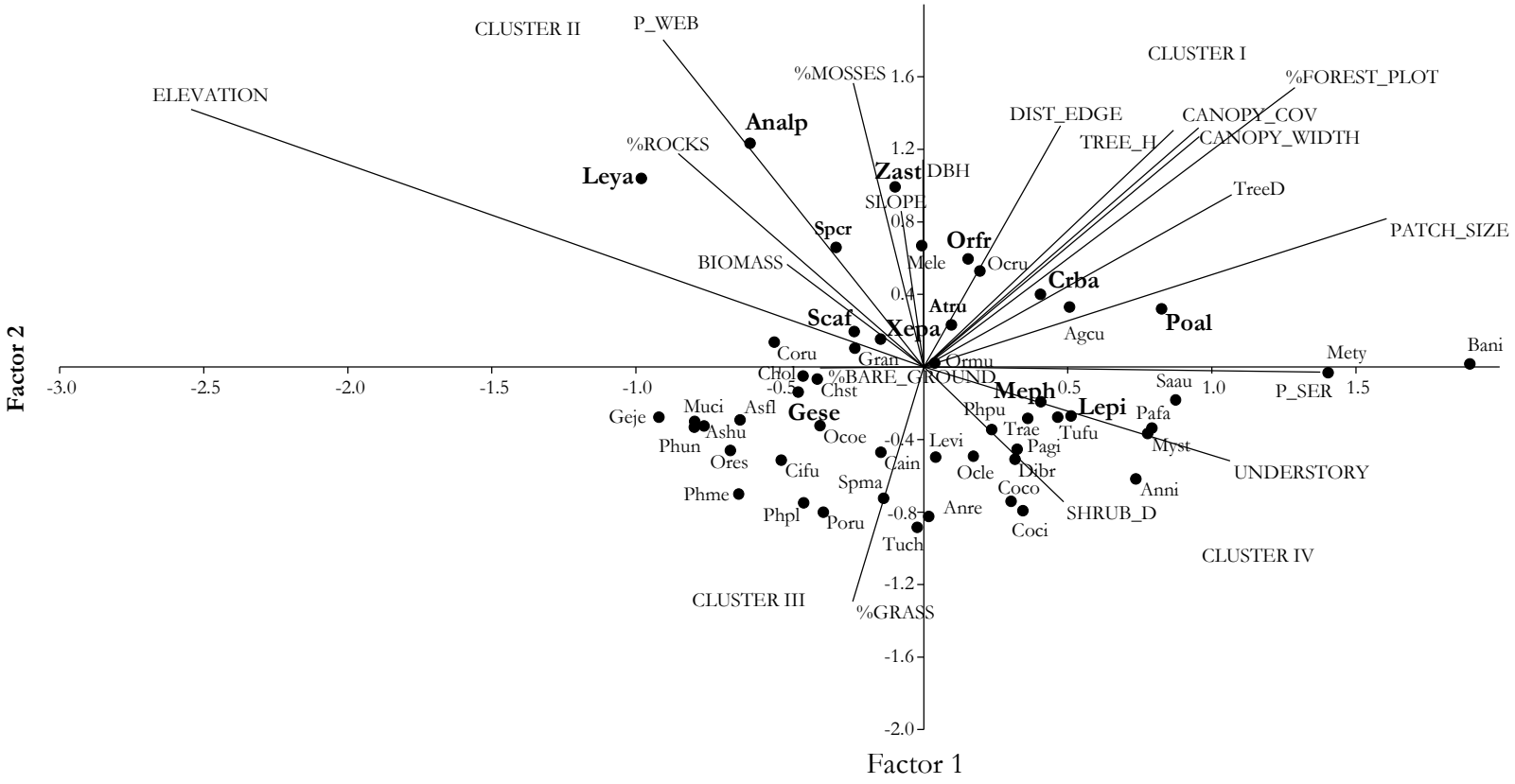


Fig. 26. Ordination of 50 bird species (points) within 19 environmental variables (upper case) for the first two canonical factors from the CCA (x & y axes). For cluster descriptions: see text. Bird species of concern are in bold type. Agcu: *Aglaeactis cupripennis*; **Analp: *Anairetes alpinus***; Anni: *Anairetes nigrocristatus*; Anre: *Anairetes reguloides*; Asfl: *Asthenes flamulata*;Ashu: *Asthenes humilis*; **Atru: *Atlapetes rufigenis***; Bani: *Basileuterus nigrocristatus*; Cain: *Catamenia inornata*; Chol: *Chalcostigma olivaceum*; Chst: *Chalcostigma stanleyii*; Cifu: *Cinclodes fuscus*; Coru: *Colaptes rupicula*; Coco: *Colibri coruscans*; Coci:*Conirostrum cinereum*; **Crba: *Cranioleuca baroni***; Dibr:*Diglossa bruneiventris*; **Gran: *Grallaria andicolus***; **Lepi: *Leptasthenura pileata*; Leya: *Leptasthenura yanacensis***; Levi: *Lesbia victoridae*; Mele: *Mecocerculus leucophrys*; **Meph: *Metallura phoebe***; Mety: *Metallura tyriantina*; Muci:*Muxisacsicola cinerea*; Myst: *Myioteretes striaticollis*; Ocle:*Octhoeca leucophrys*; Ocoe: *Octhoeca oenantoides*; Ocru:*Octhoeca rufipectoralis*; Ormu: *Orochelidon murina*; **Orfr:*Oreomanes fraseri***; Ores:*Oreotrochilus stella*; Pafa: *Patagioenas faciata*; Pagi:*Patagonas gigas*; Phme: *Phalcoboenus melanopterus*; Phpl: *Phrygilus plebejus*; Phpu:*Phrygilus punensis*; Phun: *Prhygilus unicolor*; Poru: *Polioxolmis rufipennis*;**Poal:*Poospiza alticola***; Saau:*Saltator aurantirostris*; **Scaf:*Scitalophus affinis***; Spcr:*Spinus crassirostris*; Spma: *Spinus magellanicus*; Trae:*Troglodites aedon*; Tuch:*Turdus chiguanco*; Tufu: *Turdus fuscater*; Geje: *Geocerthia jelski*; **Gese: *Geocerthia serrana***; **Xepa: *Xenodacnis parina***; **Zast: *Zaratornis stresemanni***.



APPENDIX

APPENDIX A. Number of observations with proportion (e.g. 91(0.03)) of the total number of observation showed at the base of the table (1), for each of the five glacial valleys during the dry and wet season. The total counts for each season summed across valleys are in the last three columns. Foraging guilds were assigned based on direct observations and literature review (Fjeldså and Krabbe, 1989; Lloyd, 2008).

Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Aeronautes andecolus	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	6 (0.003)	6 (0.002)	0 (0)	8 (0.001)	8 (0)	Insectivore
Aglaeactis cupripennis	36 (0.026)	91 (0.03)	127 (0.028)	0 (0)	3 (0.002)	3 (0.001)	59 (0.038)	121 (0.039)	180 (0.039)	87 (0.083)	134 (0.065)	221 (0.071)	18 (0.02)	22 (0.011)	40 (0.014)	200 (0.035)	371 (0.032)	571 (0.033)	Nectarivore
Agriornis montanus	0 (0)	5 (0.002)	5 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.001)	3 (0.001)	0 (0)	3 (0.001)	3 (0.001)	2 (0.002)	1 (0.001)	3 (0.001)	2 (0)	12 (0.001)	14 (0.001)	Insectivore
Ampelion rubricristatus	3 (0.002)	15 (0.005)	18 (0.004)	0 (0)	1 (0.001)	1 (0)	5 (0.003)	0 (0)	5 (0.001)	0 (0)	1 (0)	1 (0)	0 (0)	20 (0.01)	20 (0.007)	8 (0.001)	37 (0.003)	45 (0.003)	Frugivore
Anairetes alpinus	0 (0)	3 (0.001)	3 (0.001)	21 (0.025)	17 (0.011)	38 (0.016)	1 (0.001)	0 (0)	1 (0)	13 (0.012)	24 (0.012)	37 (0.012)	2 (0.002)	1 (0.001)	3 (0.001)	37 (0.006)	45 (0.004)	82 (0.005)	Insectivore
Anairetes flavirostris	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.001)	1 (0)	3 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	1 (0)	2 (0)	2 (0)	4 (0)	Insectivore
Anairetes nigrocristatus	8 (0.006)	21 (0.007)	29 (0.006)	0 (0)	0 (0)	0 (0)	33 (0.021)	26 (0.008)	59 (0.013)	2 (0.002)	4 (0.002)	6 (0.002)	3 (0.003)	3 (0.002)	6 (0.002)	46 (0.008)	54 (0.005)	100 (0.006)	Insectivore
Anairetes reguloides	0 (0)	2 (0.001)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	24 (0.008)	24 (0.005)	0 (0)	2 (0.001)	2 (0.001)	15 (0.017)	18 (0.009)	33 (0.012)	15 (0.003)	46 (0.004)	61 (0.004)	Insectivore
Anas flavirostris	0 (0)	5 (0.002)	5 (0.001)	0 (0)	1 (0.001)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	7 (0.001)	7 (0)	Acuatic
Anthus bogotensis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	Terrestrial Insectivore
Asthenes flammulata	10 (0.007)	70 (0.023)	80 (0.018)	2 (0.002)	3 (0.002)	5 (0.002)	20 (0.013)	79 (0.026)	99 (0.021)	12 (0.011)	19 (0.009)	31 (0.01)	17 (0.019)	29 (0.015)	46 (0.016)	61 (0.011)	200 (0.017)	261 (0.015)	Terrestrial Insectivore
Asthenes humilis	38 (0.027)	90 (0.029)	128 (0.029)	15 (0.018)	18 (0.012)	33 (0.014)	30 (0.019)	53 (0.017)	83 (0.018)	19 (0.018)	29 (0.014)	48 (0.015)	25 (0.028)	37 (0.019)	62 (0.022)	127 (0.022)	227 (0.019)	354 (0.02)	Terrestrial Insectivore
Asthenes modesta	0 (0)	0 (0)	0 (0)	0 (0)	5 (0.003)	5 (0.002)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.002)	4 (0.001)	0 (0)	9 (0.001)	9 (0.001)	Terrestrial Insectivore
Asthenes pudibunda	4 (0.003)	4 (0.001)	8 (0.002)	0 (0)	1 (0.001)	1 (0)	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	2 (0.002)	3 (0.002)	5 (0.002)	7 (0.001)	8 (0.001)	15 (0.001)	Terrestrial Insectivore
Atlapetes rufigenis	68 (0.048)	91 (0.03)	159 (0.036)	42 (0.05)	48 (0.031)	90 (0.038)	46 (0.03)	70 (0.023)	116 (0.025)	24 (0.023)	11 (0.005)	35 (0.011)	27 (0.03)	46 (0.024)	73 (0.026)	207 (0.036)	266 (0.023)	473 (0.027)	Terrestrial Insectivore
Myiothlypis nigrocristata	28 (0.02)	106 (0.035)	134 (0.03)	0 (0)	0 (0)	0 (0)	32 (0.021)	24 (0.008)	56 (0.012)	0 (0)	0 (0)	0 (0)	36 (0.04)	66 (0.034)	102 (0.036)	96 (0.017)	196 (0.017)	292 (0.017)	Insectivore

Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Bolborhynchus orbygnesius	0 (0)	3 (0.001)	3 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.002)	1 (0.001)	3 (0.001)	2 (0)	4 (0)	6 (0)	Frugivore
Caprimulgus longirostris	4 (0.003)	0 (0)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.001)	2 (0)	1 (0.001)	1 (0)	2 (0.001)	2 (0.002)	0 (0)	2 (0.001)	7 (0.001)	3 (0)	10 (0.001)	Insectivore
Catamenia analis	1 (0.001)	2 (0.001)	3 (0.001)	1 (0.001)	0 (0)	1 (0)	2 (0.001)	0 (0)	2 (0)	1 (0.001)	0 (0)	1 (0)	1 (0.001)	2 (0.001)	3 (0.001)	6 (0.001)	4 (0)	10 (0.001)	Granivore
Catamenia inornata	28 (0.02)	67 (0.022)	95 (0.021)	5 (0.006)	9 (0.006)	14 (0.006)	33 (0.021)	151 (0.049)	184 (0.04)	7 (0.007)	27 (0.013)	34 (0.011)	3 (0.003)	66 (0.034)	69 (0.024)	76 (0.013)	320 (0.027)	396 (0.023)	Granivore
Chalcostigma olivaceum	5 (0.004)	23 (0.007)	28 (0.006)	3 (0.004)	11 (0.007)	14 (0.006)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.001)	2 (0.001)	1 (0.001)	1 (0.001)	2 (0.001)	9 (0.002)	37 (0.003)	46 (0.003)	Nectarivore
Chalcostigma stanleyi	29 (0.021)	70 (0.023)	99 (0.022)	19 (0.023)	37 (0.024)	56 (0.024)	28 (0.018)	13 (0.004)	41 (0.009)	8 (0.008)	2 (0.001)	10 (0.003)	6 (0.007)	24 (0.013)	30 (0.011)	90 (0.016)	146 (0.013)	236 (0.014)	Nectarivore
Chloephaga melanoptera	0 (0)	6 (0.002)	6 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	7 (0.001)	7 (0)	Acuatic
Chroicocephalus serranus	1 (0.001)	3 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	2 (0)	3 (0)	5 (0)	Acuatic
Cinclodes atacamensis	0 (0)	10 (0.003)	10 (0.002)	0 (0)	5 (0.003)	5 (0.002)	0 (0)	15 (0.005)	15 (0.003)	7 (0.007)	23 (0.011)	30 (0.01)	5 (0.006)	5 (0.003)	10 (0.004)	12 (0.002)	58 (0.005)	70 (0.004)	Terrestrial Insectivore
Cinclodes fuscus	64 (0.046)	147 (0.048)	211 (0.047)	65 (0.077)	63 (0.041)	128 (0.054)	48 (0.031)	61 (0.02)	109 (0.024)	47 (0.045)	121 (0.058)	168 (0.054)	18 (0.02)	34 (0.018)	52 (0.018)	242 (0.042)	426 (0.037)	668 (0.038)	Terrestrial Insectivore
Cinclus leucocephalus	0 (0)	1 (0)	1 (0)	0 (0)	3 (0.002)	3 (0.001)	3 (0.002)	11 (0.004)	14 (0.003)	0 (0)	1 (0)	1 (0)	0 (0)	1 (0.001)	1 (0)	3 (0.001)	17 (0.001)	20 (0.001)	Insectivore
Coeligena iris	0 (0)	12 (0.004)	12 (0.003)	0 (0)	1 (0.001)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5 (0.006)	7 (0.004)	12 (0.004)	5 (0.001)	20 (0.002)	25 (0.001)	Nectarivore
Colaptes rupicola	11 (0.008)	33 (0.011)	44 (0.01)	24 (0.029)	60 (0.039)	84 (0.035)	30 (0.019)	64 (0.021)	94 (0.02)	8 (0.008)	70 (0.034)	78 (0.025)	0 (0)	9 (0.005)	9 (0.003)	73 (0.013)	236 (0.02)	309 (0.018)	Terrestrial Insectivore
Colibri coruscans	11 (0.008)	0 (0)	11 (0.002)	0 (0)	0 (0)	0 (0)	39 (0.025)	43 (0.014)	82 (0.018)	5 (0.005)	0 (0)	5 (0.002)	0 (0)	4 (0.002)	4 (0.001)	55 (0.01)	47 (0.004)	102 (0.006)	Nectarivore
Columbina cruziana	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	1 (0)	Frugivore
Conirostrum cinereum	10 (0.007)	29 (0.009)	39 (0.009)	1 (0.001)	0 (0)	1 (0)	12 (0.008)	46 (0.015)	58 (0.013)	3 (0.003)	11 (0.005)	14 (0.004)	4 (0.004)	16 (0.008)	20 (0.007)	30 (0.005)	102 (0.009)	132 (0.008)	Insectivore
Cranioleuca antisiensis	87 (0.062)	157 (0.051)	244 (0.055)	30 (0.036)	89 (0.058)	119 (0.05)	76 (0.049)	103 (0.033)	179 (0.039)	37 (0.035)	59 (0.029)	96 (0.031)	73 (0.081)	134 (0.07)	207 (0.073)	303 (0.053)	542 (0.046)	845 (0.049)	Insectivore
Diglossa bruneiventris	11 (0.008)	15 (0.005)	26 (0.006)	0 (0)	1 (0.001)	1 (0)	26 (0.017)	71 (0.023)	97 (0.021)	3 (0.003)	25 (0.012)	28 (0.009)	8 (0.009)	10 (0.005)	18 (0.006)	48 (0.008)	122 (0.01)	170 (0.01)	Insectivore
Diglossa sittoides	0 (0)	2 (0.001)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (0.001)	6 (0)	Insectivore

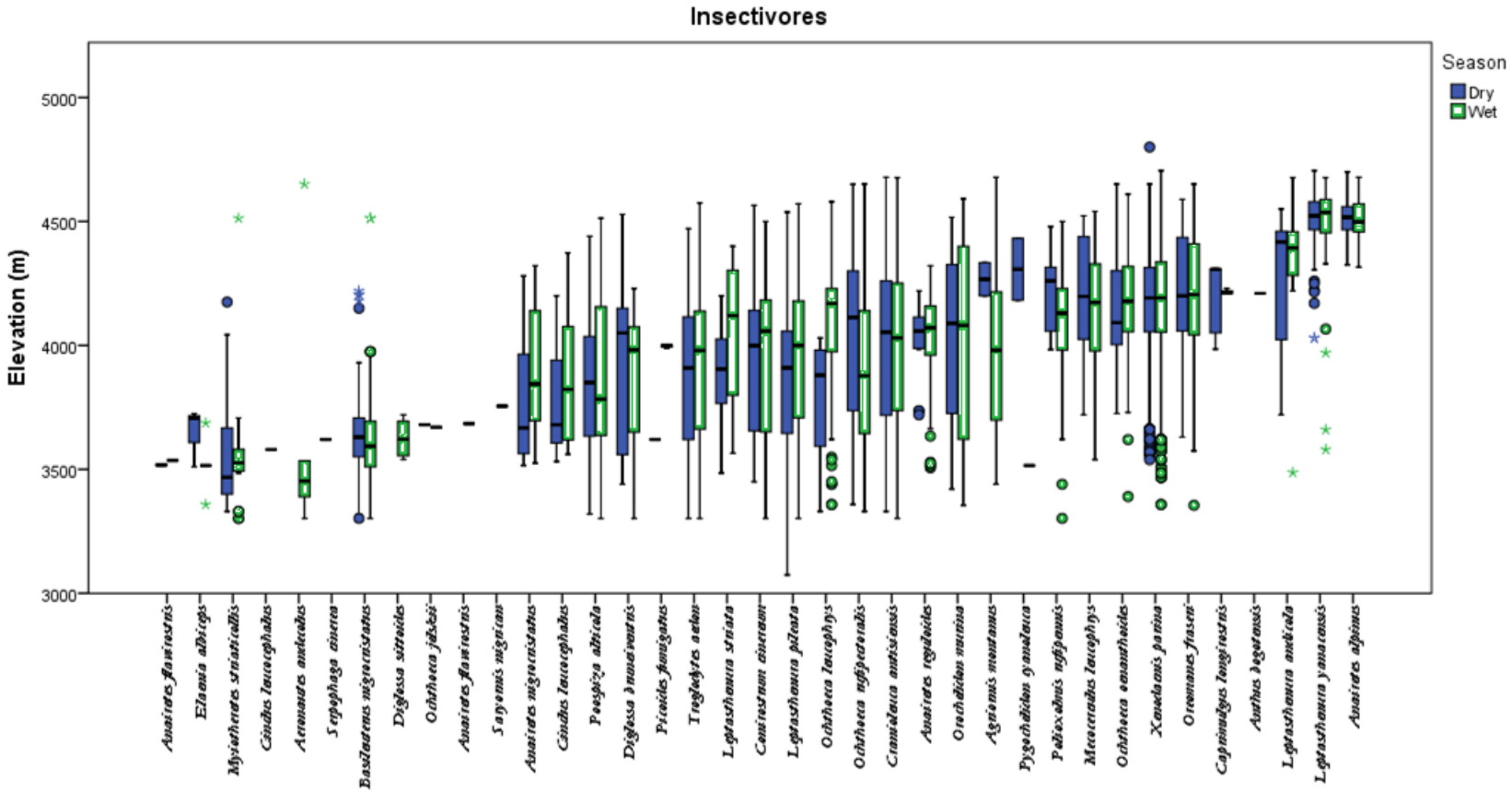
Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Diuca speculifera	2 (0.001)	4 (0.001)	6 (0.001)	6 (0.007)	9 (0.006)	15 (0.006)	5 (0.003)	0 (0)	5 (0.001)	11 (0.011)	12 (0.006)	23 (0.007)	1 (0.001)	0 (0)	1 (0)	25 (0.004)	25 (0.002)	50 (0.003)	Granivore
Elaenia albiceps	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	10 (0.003)	10 (0.002)	0 (0)	0 (0)	0 (0)	3 (0.003)	1 (0.001)	4 (0.001)	3 (0.001)	11 (0.001)	14 (0.001)	Insectivore
Falco femoralis	1 (0.001)	1 (0)	2 (0)	0 (0)	2 (0.001)	2 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	3 (0)	4 (0)	Carnivore
Falco sparverius	1 (0.001)	2 (0.001)	3 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	2 (0)	3 (0)	5 (0)	Carnivore
Fulica ardesiaca	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	Acuatic
Gallinago andina	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	1 (0)	Acuatic
Geranoaetus melanoleucus	0 (0)	2 (0.001)	2 (0)	1 (0.001)	2 (0.001)	3 (0.001)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	5 (0)	6 (0)	Carnivore
Geranoaetus polyosoma	0 (0)	2 (0.001)	2 (0)	2 (0.002)	0 (0)	2 (0.001)	5 (0.003)	11 (0.004)	16 (0.003)	2 (0.002)	5 (0.002)	7 (0.002)	1 (0.001)	1 (0.001)	2 (0.001)	10 (0.002)	19 (0.002)	29 (0.002)	Carnivore
Grallaria andicolus	49 (0.035)	96 (0.031)	145 (0.032)	30 (0.036)	95 (0.062)	125 (0.053)	25 (0.016)	89 (0.029)	114 (0.025)	40 (0.038)	75 (0.036)	115 (0.037)	10 (0.011)	74 (0.039)	84 (0.03)	154 (0.027)	429 (0.037)	583 (0.033)	Terrestrial Insectivore
Incaspiza personata	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	3 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	3 (0)	4 (0)	Granivore
Leptasthenura andicola	6 (0.004)	9 (0.003)	15 (0.003)	3 (0.004)	6 (0.004)	9 (0.004)	0 (0)	1 (0)	1 (0)	2 (0.002)	1 (0)	3 (0.001)	0 (0)	5 (0.003)	5 (0.002)	11 (0.002)	22 (0.002)	33 (0.002)	Insectivore
Leptasthenura pileata	36 (0.026)	114 (0.037)	150 (0.034)	7 (0.008)	15 (0.01)	22 (0.009)	34 (0.022)	74 (0.024)	108 (0.023)	6 (0.006)	47 (0.023)	53 (0.017)	41 (0.045)	138 (0.072)	179 (0.063)	124 (0.022)	388 (0.033)	512 (0.029)	Insectivore
Leptasthenura striata	5 (0.004)	2 (0.001)	7 (0.002)	0 (0)	2 (0.001)	2 (0.001)	3 (0.002)	0 (0)	3 (0.001)	1 (0.001)	0 (0)	1 (0)	7 (0.008)	0 (0)	7 (0.002)	16 (0.003)	4 (0)	20 (0.001)	Insectivore
Leptasthenura yanacensis	2 (0.001)	3 (0.001)	5 (0.001)	52 (0.062)	55 (0.036)	107 (0.045)	1 (0.001)	2 (0.001)	3 (0.001)	21 (0.02)	36 (0.017)	57 (0.018)	9 (0.01)	4 (0.002)	13 (0.005)	85 (0.015)	100 (0.009)	185 (0.011)	Insectivore
Lesbia nuna	3 (0.002)	2 (0.001)	5 (0.001)	0 (0)	0 (0)	0 (0)	5 (0.003)	9 (0.003)	14 (0.003)	1 (0.001)	0 (0)	1 (0)	0 (0)	2 (0.001)	2 (0.001)	9 (0.002)	13 (0.001)	22 (0.001)	Nectarivore
Lesbia victoriae	1 (0.001)	16 (0.005)	17 (0.004)	0 (0)	4 (0.003)	4 (0.002)	10 (0.006)	44 (0.014)	54 (0.012)	1 (0.001)	3 (0.001)	4 (0.001)	2 (0.002)	12 (0.006)	14 (0.005)	14 (0.002)	79 (0.007)	93 (0.005)	Nectarivore
Lophonetta specularioides	1 (0.001)	2 (0.001)	3 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	3 (0)	4 (0)	Acuatic
Mecocerculus leucophrys	5 (0.004)	5 (0.002)	10 (0.002)	23 (0.027)	14 (0.009)	37 (0.016)	13 (0.008)	21 (0.007)	34 (0.007)	2 (0.002)	4 (0.002)	6 (0.002)	14 (0.016)	19 (0.01)	33 (0.012)	57 (0.01)	63 (0.005)	120 (0.007)	Insectivore
Megascops koepckeae	1 (0.001)	2 (0.001)	3 (0.001)	0 (0)	1 (0.001)	1 (0)	2 (0.001)	2 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	4 (0.004)	4 (0.002)	8 (0.003)	7 (0.001)	9 (0.001)	16 (0.001)	Carnivore

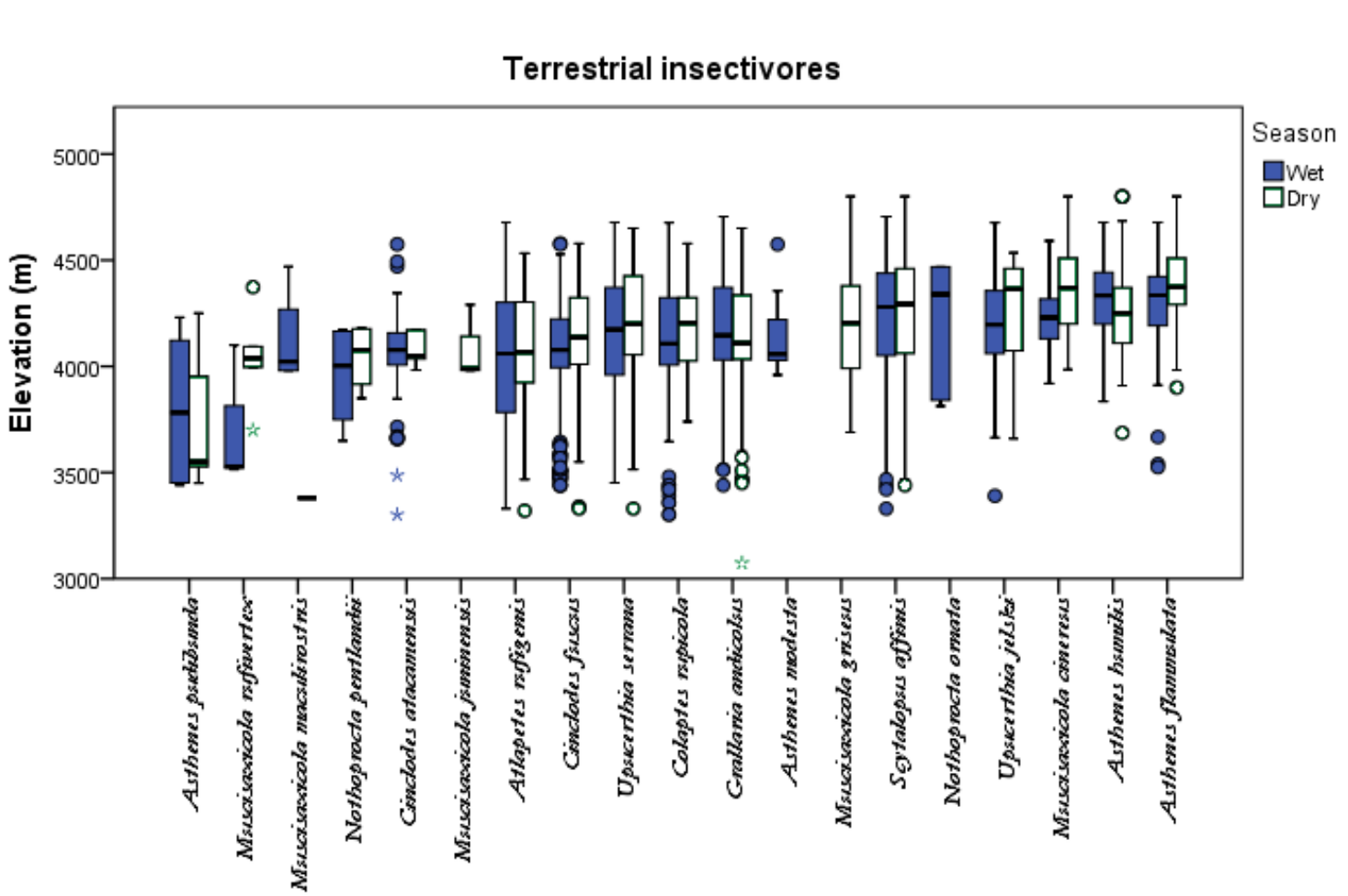
Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Merganetta armata	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	2 (0.001)	3 (0.001)	5 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.002)	3 (0.001)	3 (0.001)	6 (0.001)	9 (0.001)	Acuatic
Metallura phoebe	60 (0.043)	138 (0.045)	198 (0.044)	12 (0.014)	21 (0.014)	33 (0.014)	57 (0.037)	112 (0.036)	169 (0.036)	19 (0.018)	11 (0.005)	30 (0.01)	46 (0.051)	90 (0.047)	136 (0.048)	194 (0.034)	372 (0.032)	566 (0.033)	Nectarivore
Metallura tyrianthina	20 (0.014)	33 (0.011)	53 (0.012)	4 (0.005)	0 (0)	4 (0.002)	11 (0.007)	7 (0.002)	18 (0.004)	0 (0)	0 (0)	0 (0)	23 (0.025)	20 (0.01)	43 (0.015)	58 (0.01)	60 (0.005)	118 (0.007)	Nectarivore
Metriopelia melanoptera	2 (0.001)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	2 (0.002)	0 (0)	2 (0.001)	4 (0.001)	1 (0)	5 (0)	Frugivore
Muscisaxicola cinereus	3 (0.002)	7 (0.002)	10 (0.002)	3 (0.004)	2 (0.001)	5 (0.002)	3 (0.002)	14 (0.005)	17 (0.004)	5 (0.005)	2 (0.001)	7 (0.002)	14 (0.016)	5 (0.003)	19 (0.007)	28 (0.005)	30 (0.003)	58 (0.003)	Terrestrial Insectivore
Muscisaxicola griseus	3 (0.002)	0 (0)	3 (0.001)	12 (0.014)	0 (0)	12 (0.005)	10 (0.006)	0 (0)	10 (0.002)	9 (0.009)	1 (0)	10 (0.003)	1 (0.001)	0 (0)	1 (0)	35 (0.006)	1 (0)	36 (0.002)	Terrestrial Insectivore
Muscisaxicola juninensis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.003)	0 (0)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.001)	0 (0)	4 (0)	Terrestrial Insectivore
Muscisaxicola maculirostris	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	1 (0)	0 (0)	3 (0.001)	3 (0.001)	0 (0)	3 (0.001)	3 (0.001)	1 (0.001)	0 (0)	1 (0)	1 (0)	7 (0.001)	8 (0)	Terrestrial Insectivore
Muscisaxicola rufivertex	0 (0)	1 (0)	1 (0)	1 (0.001)	0 (0)	1 (0)	3 (0.002)	2 (0.001)	5 (0.001)	2 (0.002)	0 (0)	2 (0.001)	0 (0)	0 (0)	0 (0)	6 (0.001)	3 (0)	9 (0.001)	Terrestrial Insectivore
Myiotheretes striaticollis	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	8 (0.005)	8 (0.003)	16 (0.003)	0 (0)	0 (0)	0 (0)	12 (0.013)	11 (0.006)	23 (0.008)	20 (0.003)	20 (0.002)	40 (0.002)	Insectivore
Nothoprocta ornata	0 (0)	2 (0.001)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (0.001)	6 (0)	Terrestrial Insectivore
Nothoprocta pentlandii	3 (0.002)	1 (0)	4 (0.001)	0 (0)	0 (0)	0 (0)	1 (0.001)	3 (0.001)	4 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.001)	4 (0)	8 (0)	Terrestrial Insectivore
Nycticorax nycticorax	1 (0.001)	4 (0.001)	5 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	4 (0)	5 (0)	Acuatic
Ochthoeca jelskii	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	1 (0)	1 (0)	2 (0)	Insectivore
Ochthoeca leucophrys	6 (0.004)	5 (0.002)	11 (0.002)	0 (0)	2 (0.001)	2 (0.001)	7 (0.004)	31 (0.01)	38 (0.008)	0 (0)	1 (0)	1 (0)	11 (0.012)	25 (0.013)	36 (0.013)	24 (0.004)	64 (0.005)	88 (0.005)	Insectivore
Ochthoeca oenanthoides	15 (0.011)	17 (0.006)	32 (0.007)	8 (0.01)	43 (0.028)	51 (0.022)	21 (0.013)	66 (0.021)	87 (0.019)	30 (0.029)	86 (0.042)	116 (0.037)	11 (0.012)	40 (0.021)	51 (0.018)	85 (0.015)	252 (0.022)	337 (0.019)	Insectivore
Ochthoeca rufipectoralis	15 (0.011)	21 (0.007)	36 (0.008)	27 (0.032)	11 (0.007)	38 (0.016)	33 (0.021)	17 (0.006)	50 (0.011)	18 (0.017)	11 (0.005)	29 (0.009)	25 (0.028)	30 (0.016)	55 (0.02)	118 (0.021)	90 (0.008)	208 (0.012)	Insectivore
Oreomanes fraseri	16 (0.011)	32 (0.01)	48 (0.011)	25 (0.03)	22 (0.014)	47 (0.02)	24 (0.015)	35 (0.011)	59 (0.013)	23 (0.022)	33 (0.016)	56 (0.018)	28 (0.031)	37 (0.019)	65 (0.023)	116 (0.02)	159 (0.014)	275 (0.016)	Insectivore
Oreotrochilus estella	0 (0)	0 (0)	0 (0)	5 (0.006)	10 (0.007)	15 (0.006)	19 (0.012)	4 (0.001)	23 (0.005)	13 (0.012)	9 (0.004)	22 (0.007)	4 (0.004)	3 (0.002)	7 (0.002)	41 (0.007)	26 (0.002)	67 (0.004)	Nectarivore

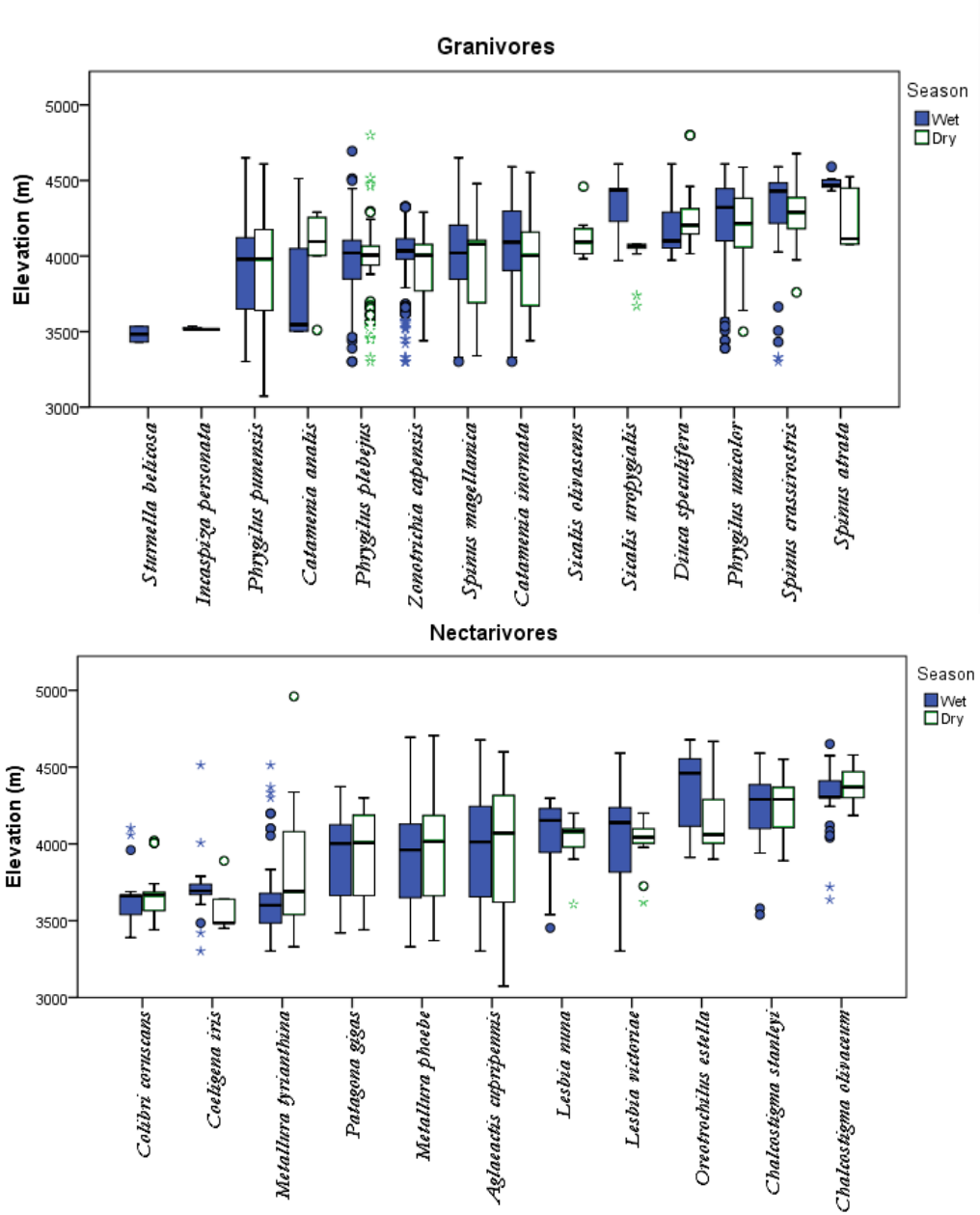
Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Orochelidon murina	0 (0)	19 (0.006)	19 (0.004)	9 (0.011)	22 (0.014)	31 (0.013)	4 (0.003)	38 (0.012)	42 (0.009)	3 (0.003)	29 (0.014)	32 (0.01)	6 (0.007)	53 (0.028)	59 (0.021)	22 (0.004)	161 (0.014)	183 (0.011)	Insectivore
Oxyura jamaicensis	0 (0)	2 (0.001)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)	2 (0)	Acuatic
Patagioenas fasciata	0 (0)	3 (0.001)	3 (0.001)	0 (0)	0 (0)	0 (0)	16 (0.01)	7 (0.002)	23 (0.005)	0 (0)	0 (0)	0 (0)	3 (0.003)	3 (0.002)	6 (0.002)	19 (0.003)	13 (0.001)	32 (0.002)	Frugivore
Patagona gigas	14 (0.01)	42 (0.014)	56 (0.013)	3 (0.004)	3 (0.002)	6 (0.003)	21 (0.013)	34 (0.011)	55 (0.012)	10 (0.01)	11 (0.005)	21 (0.007)	4 (0.004)	12 (0.006)	16 (0.006)	52 (0.009)	102 (0.009)	154 (0.009)	Insectivore
Phalcoboenus megalopterus	0 (0)	5 (0.002)	5 (0.001)	0 (0)	1 (0.001)	1 (0)	3 (0.002)	22 (0.007)	25 (0.005)	1 (0.001)	6 (0.003)	7 (0.002)	0 (0)	1 (0.001)	1 (0)	4 (0.001)	35 (0.003)	39 (0.002)	Carnivore
Phrygilus plebejus	22 (0.016)	81 (0.026)	103 (0.023)	1 (0.001)	21 (0.014)	22 (0.009)	61 (0.039)	60 (0.019)	121 (0.026)	82 (0.078)	79 (0.038)	161 (0.052)	21 (0.023)	26 (0.014)	47 (0.017)	187 (0.032)	267 (0.023)	454 (0.026)	Granivore
Phrygilus punensis	22 (0.016)	49 (0.016)	71 (0.016)	13 (0.015)	9 (0.006)	22 (0.009)	35 (0.022)	96 (0.031)	131 (0.028)	13 (0.012)	50 (0.024)	63 (0.02)	19 (0.021)	117 (0.061)	136 (0.048)	102 (0.018)	321 (0.028)	423 (0.024)	Granivore
Phrygilus unicolor	22 (0.016)	29 (0.009)	51 (0.011)	35 (0.042)	56 (0.037)	91 (0.038)	24 (0.015)	30 (0.01)	54 (0.012)	19 (0.018)	33 (0.016)	52 (0.017)	25 (0.028)	5 (0.003)	30 (0.011)	125 (0.022)	153 (0.013)	278 (0.016)	Granivore
Picoides fumigatus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.002)	3 (0.001)	1 (0)	3 (0)	4 (0)	Insectivore
Pipraeidae bonariensis	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5 (0.002)	5 (0.001)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5 (0)	5 (0)	Frugivore
Polioxolmis rufipennis	4 (0.003)	9 (0.003)	13 (0.003)	0 (0)	5 (0.003)	5 (0.002)	6 (0.004)	16 (0.005)	22 (0.005)	3 (0.003)	8 (0.004)	11 (0.004)	2 (0.002)	5 (0.003)	7 (0.002)	15 (0.003)	43 (0.004)	58 (0.003)	Insectivore
Poospiza alticola	48 (0.034)	56 (0.018)	104 (0.023)	10 (0.012)	9 (0.006)	19 (0.008)	13 (0.008)	18 (0.006)	31 (0.007)	1 (0.001)	1 (0)	2 (0.001)	35 (0.039)	21 (0.011)	56 (0.02)	107 (0.019)	105 (0.009)	212 (0.012)	Insectivore
Psilopsiagon aurifrons	0 (0)	1 (0)	1 (0)	0 (0)	1 (0.001)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0)	2 (0)	Frugivore
Pygochelidon cyanoleuca	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	2 (0.002)	0 (0)	2 (0.001)	0 (0)	0 (0)	0 (0)	2 (0)	1 (0)	3 (0)	Insectivore
Rollandia rolland	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (0.004)	0 (0)	4 (0.001)	4 (0.001)	0 (0)	4 (0)	Acuatic
Saltator aurantirostris	0 (0)	3 (0.001)	3 (0.001)	0 (0)	0 (0)	0 (0)	4 (0.003)	39 (0.013)	43 (0.009)	0 (0)	1 (0)	1 (0)	0 (0)	6 (0.003)	6 (0.002)	4 (0.001)	49 (0.004)	53 (0.003)	Frugivore
Saryornis nigrican	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	1 (0)	0 (0)	1 (0)	1 (0)	Insectivore
Scytalopus affinis	62 (0.044)	116 (0.038)	178 (0.04)	35 (0.042)	89 (0.058)	124 (0.052)	48 (0.031)	145 (0.047)	193 (0.042)	41 (0.039)	84 (0.041)	125 (0.04)	36 (0.04)	88 (0.046)	124 (0.044)	222 (0.039)	522 (0.045)	744 (0.043)	Insectivore
Serpophaga cinerea	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0)	0 (0)	1 (0)	Insectivore

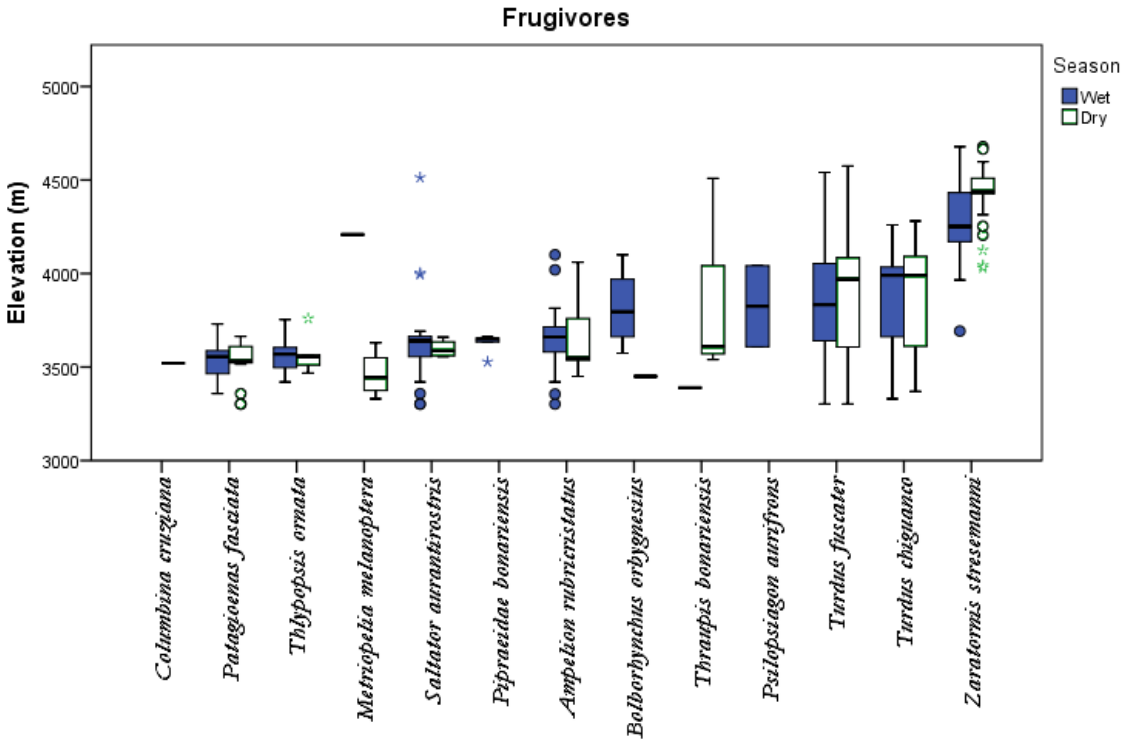
Species	Llanganuco			Llaca			Ulta			Rajucolta			Paron			Total			Guild
	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	Dry	Wet	Total	
Sicalis olivascens	0 (0)	0 (0)	0 (0)	5 (0.006)	0 (0)	5 (0.002)	0 (0)	0 (0)	0 (0)	8 (0.008)	0 (0)	8 (0.003)	0 (0)	0 (0)	0 (0)	13 (0.002)	0 (0)	13 (0.001)	Granivore
Sicalis uropygialis	0 (0)	0 (0)	0 (0)	0 (0)	9 (0.006)	9 (0.004)	2 (0.001)	4 (0.001)	6 (0.001)	11 (0.011)	15 (0.007)	26 (0.008)	0 (0)	0 (0)	0 (0)	13 (0.002)	28 (0.002)	41 (0.002)	Granivore
Spinus atrata	0 (0)	0 (0)	0 (0)	5 (0.006)	6 (0.004)	11 (0.005)	0 (0)	0 (0)	0 (0)	6 (0.006)	4 (0.002)	10 (0.003)	0 (0)	1 (0.001)	1 (0)	11 (0.002)	11 (0.001)	22 (0.001)	Granivore
Spinus crassirostris	2 (0.001)	1 (0)	3 (0.001)	1 (0.001)	4 (0.003)	5 (0.002)	3 (0.002)	25 (0.008)	28 (0.006)	7 (0.007)	8 (0.004)	15 (0.005)	5 (0.006)	16 (0.008)	21 (0.007)	18 (0.003)	54 (0.005)	72 (0.004)	Granivore
Spinus magellanica	3 (0.002)	16 (0.005)	19 (0.004)	0 (0)	1 (0.001)	1 (0)	12 (0.008)	3 (0.001)	15 (0.003)	19 (0.018)	13 (0.006)	32 (0.01)	4 (0.004)	4 (0.002)	8 (0.003)	38 (0.007)	37 (0.003)	75 (0.004)	Granivore
Sturnella belicosa	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.001)	2 (0.001)	0 (0)	2 (0)	2 (0)	Granivore
Thlypopsis ornata	1 (0.001)	10 (0.003)	11 (0.002)	0 (0)	0 (0)	0 (0)	2 (0.001)	1 (0)	3 (0.001)	0 (0)	0 (0)	0 (0)	2 (0.002)	1 (0.001)	3 (0.001)	5 (0.001)	12 (0.001)	17 (0.001)	Frugivore
Thraupis bonariensis	1 (0.001)	0 (0)	1 (0)	1 (0.001)	0 (0)	1 (0)	6 (0.004)	0 (0)	6 (0.001)	0 (0)	0 (0)	0 (0)	1 (0.001)	1 (0.001)	2 (0.001)	9 (0.002)	1 (0)	10 (0.001)	Frugivore
Troglodytes aedon	28 (0.02)	212 (0.069)	240 (0.054)	12 (0.014)	77 (0.05)	89 (0.038)	60 (0.038)	216 (0.07)	276 (0.06)	26 (0.025)	127 (0.061)	153 (0.049)	23 (0.025)	196 (0.102)	219 (0.078)	149 (0.026)	828 (0.071)	977 (0.056)	Insectivore
Turdus chiguanco	4 (0.003)	3 (0.001)	7 (0.002)	1 (0.001)	0 (0)	1 (0)	9 (0.006)	19 (0.006)	28 (0.006)	7 (0.007)	23 (0.011)	30 (0.01)	4 (0.004)	4 (0.002)	8 (0.003)	25 (0.004)	49 (0.004)	74 (0.004)	Frugivore
Turdus fuscater	43 (0.031)	144 (0.047)	187 (0.042)	21 (0.025)	10 (0.007)	31 (0.013)	61 (0.039)	64 (0.021)	125 (0.027)	14 (0.013)	28 (0.014)	42 (0.013)	39 (0.043)	44 (0.023)	83 (0.029)	178 (0.031)	290 (0.025)	468 (0.027)	Frugivore
Upucerthia jelski	6 (0.004)	4 (0.001)	10 (0.002)	14 (0.017)	13 (0.009)	27 (0.011)	3 (0.002)	12 (0.004)	15 (0.003)	4 (0.004)	21 (0.01)	25 (0.008)	0 (0)	3 (0.002)	3 (0.001)	27 (0.005)	53 (0.005)	80 (0.005)	Terrestrial Insectivore
Geocerthia serrana	38 (0.027)	52 (0.017)	90 (0.02)	37 (0.044)	36 (0.024)	73 (0.031)	29 (0.019)	48 (0.016)	77 (0.017)	34 (0.032)	40 (0.019)	74 (0.024)	3 (0.003)	10 (0.005)	13 (0.005)	141 (0.024)	186 (0.016)	327 (0.019)	Terrestrial Insectivore
Vultur gryphus	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.001)	3 (0.001)	4 (0.001)	1 (0.001)	7 (0.003)	8 (0.003)	0 (0)	0 (0)	0 (0)	2 (0)	10 (0.001)	12 (0.001)	Carnivore
Xenodacnis parina	363 (0.258)	577 (0.188)	940 (0.21)	190 (0.226)	461 (0.302)	651 (0.275)	246 (0.158)	480 (0.156)	726 (0.157)	170 (0.162)	312 (0.151)	482 (0.155)	117 (0.13)	188 (0.098)	305 (0.108)	1086 (0.189)	2018 (0.173)	3104 (0.178)	Insectivore
Zaratornis stresemanni	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	4 (0.003)	36 (0.012)	40 (0.009)	34 (0.032)	151 (0.073)	185 (0.059)	2 (0.002)	0 (0)	2 (0.001)	40 (0.007)	188 (0.016)	228 (0.013)	Frugivore
Zonotrichia capensis	7 (0.005)	22 (0.007)	29 (0.006)	0 (0)	0 (0)	0 (0)	50 (0.032)	91 (0.03)	141 (0.03)	40 (0.038)	106 (0.051)	146 (0.047)	0 (0)	11 (0.006)	11 (0.004)	97 (0.017)	230 (0.02)	327 (0.019)	Granivore
Total general	1406 (1)	3067 (1)	4473 (1)	842 (1)	1526 (1)	2368 (1)	1559 (1)	3077 (1)	4636 (1)	1047 (1)	2070 (1)	3117 (1)	902 (1)	1918 (1)	2820 (1)	5756 (1)	11658 (1)	17414 (1)	

APPENDIX B. Seasonal altitudinal distributions of the *Polylepis* bird community, grouped by foraging guilds. Boxplots are constructed base on point count and systematic observations conducted between them, during the dry and wet season.

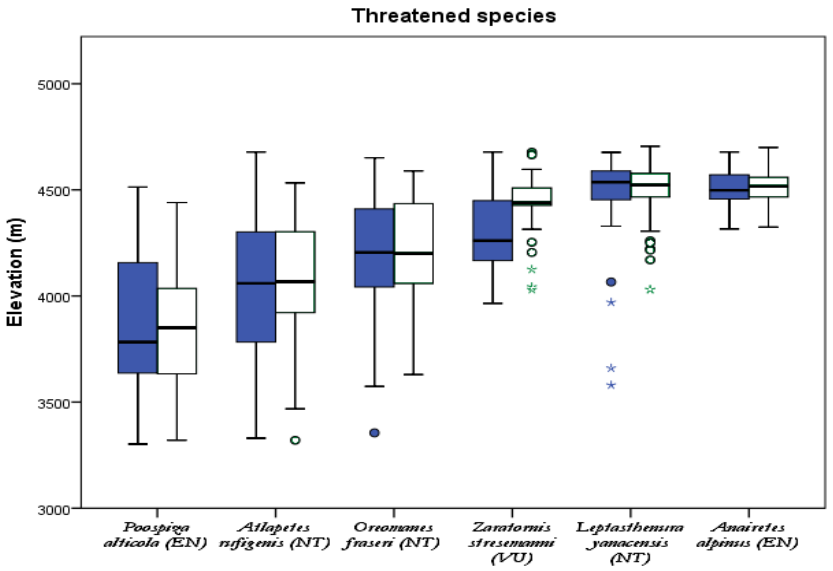


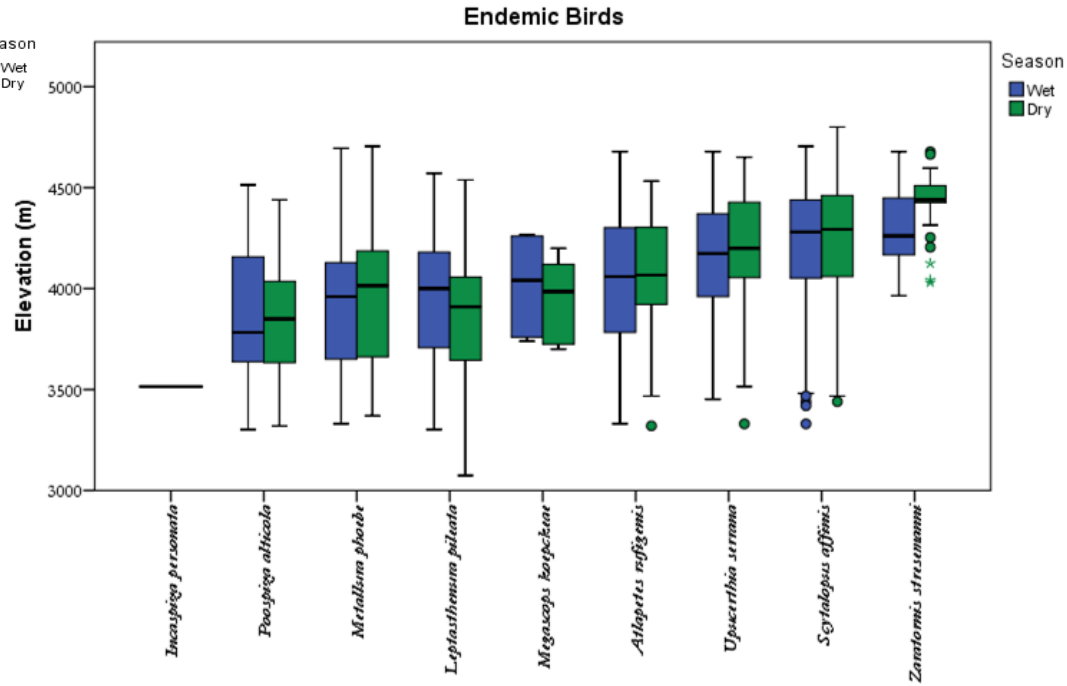

Terrestrial insectivores
Elevation (m)
5000
4500
4000
3500
3000
Season
Wet
Dry
Asthenes pudibunda
Muscisaxicola rufivertex
Muscisaxicola maculirostris
Nothoprocta pentlandii
Cinclodes atacamensis
Muscisaxicola juninensis
Atlapetes rufigenis
Cinclodes fuscus
Upucerthia serrana
Colaptes rupicola
Grallaria andicolus
Asthenes modesta
Muscisaxicola griseus
Scytalopus affinis
Nothoprocta ornata
Upucerthia jelskii
Muscisaxicola cinereus
Asthenes humilis
Asthenes flammulata


Granivores
Elevation (m)
5000
4500
4000
3500
3000
Season
Wet
Dry
Sturnella bellicosa
Incaspiza personata
Phrygilus punensis
Catamenia analis
Phrygilus plebejus
Zonotrichia capensis
Spinus magellanica
Catamenia inornata
Sicalis olivascens
Sicalis uropygialis
Diuca speculifera
Phrygilus unicolor
Spinus crassirostris
Spinus atrata
Nectarivores
Elevation (m)
5000
4500
4000
3500
3000
Season
Wet
Dry
Colibri coruscans
Coeligena iris
Metallura tyrianthina
Patagona gigas
Metallura phoebe
Aglaeactis cupripennis
Lesbia nuna
Lesbia victoriae
Oreotrochilus estella
Chalcostigma stanleyi
Chalcostigma olivaceum

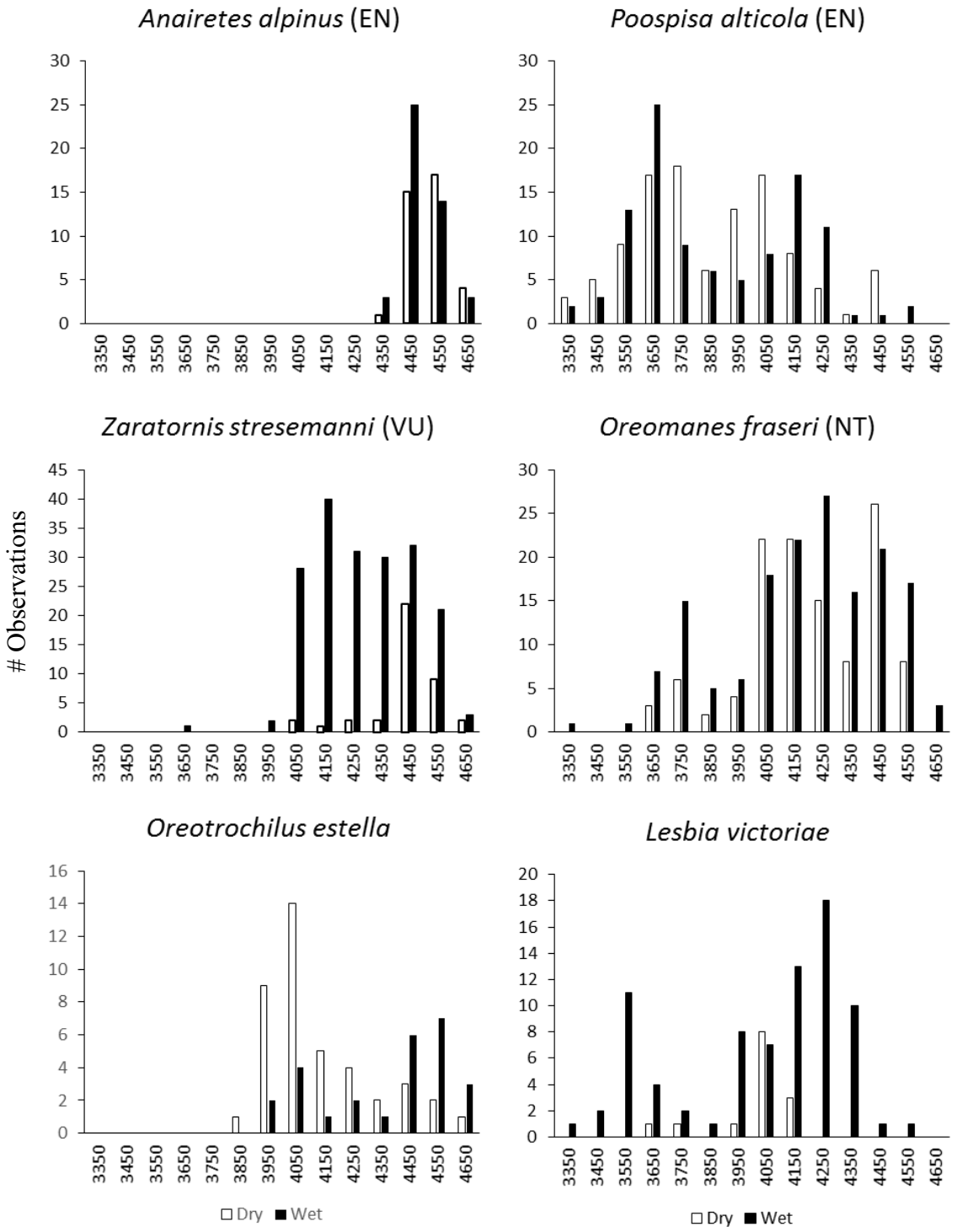

Frugivores
Elevation (m)
5000
4500
4000
3500
3000
Season
Wet
Dry
Columbina cruziana
Patagioenas fasciata
Thlypopsis ornata
Metriopelia melanoptera
Saltator aurantiirostris
Pipraeidae bonariensis
Ampelion rubricristatus
Bolborhynchus orbygnesius
Thraupis bonariensis
Psilopsiagon aurifrons
Turdus fuscater
Turdus chiguanco
Zaratornis stresemanni

APPENDIX C. Seasonal altitudinal distributions of the endemic and threatened *Polylepis* bird species. Boxplots are constructed base on point count and systematic observations conducted between them, during the dry and wet season.





APPENDIX D The degree of seasonal change in the relative abundance of different species along an elevation, suggest species-specific responses to seasonality. Here, *Z stresemanni*, *O. estella* and *L. victoriae* shown stronger changes compared to the other three bird species.



APPENDIX E UTM coordinates and ecosystemt type of 130 points surveyed durint this study along five glacial valleys in Cordillera Blanca, Huascarán National Park, Peru

Glacial Valley	Point Count IDD	Longitude	Latitude	Elevation (m)	Ecosystem
Llanganuco	PC1Loc1Alt1	0205928	8993068	3468	Shrubs
Llanganuco	PC2Loc1Alt1	0206165	8993288	3487	Polylepis forest
Llanganuco	PC3Loc1Alt1	0206611	8993640	3551	Polylepis forest
Llanganuco	PC4Loc1Alt1	0206773	8993778	3574	Polylepis forest
Llanganuco	PC5Loc1Alt1	0206967	8993906	3587	Polylepis forest
Llanganuco	PC6Loc1Alt1	0207140	8994015	3607	Polylepis forest
Llanganuco	PC7Loc1Alt1	0207448	8994118	3637	Polylepis forest
Llanganuco	PC8Loc1Alt1	0207621	8994396	3670	Polylepis forest
Llanganuco	PC9Loc1Alt1	0207972	8994764	3720	Polylepis forest
Llanganuco	PC10Loc1Alt1	0208307	8995104	3783	Polylepis forest
Llanganuco	PC11Loc1Alt2	0213053	8999028	3909	Polylepis forest
Llanganuco	PC12Loc1Alt2	0213187	8998983	3940	Shrubs
Llanganuco	PC13Loc1Alt2	0213319	8998925	3981	Shrubs
Llanganuco	PC14Loc1Alt2	0213456	8998823	3996	Polylepis forest
Llanganuco	PC15Loc1Alt2	0213629	8998775	4024	Polylepis forest
Llanganuco	PC16Loc1Alt2	0213709	8998716	4053	Polylepis forest
Llanganuco	PC17Loc1Alt2	0213856	8998607	4060	Shrubs
Llanganuco	PC18Loc1Alt2	0213950	8998637	4100	Shrubs
Llanganuco	PC19Loc1Alt2	0214043	8998590	4137	Shrubs
Llanganuco	PC20Loc1Alt2	0214045	8998696	4192	Shrubs
Llanganuco	PC21Loc1Alt3	0214144	8998589	4222	Polylepis forest
Llanganuco	PC22Loc1Alt3	0214291	8998485	4244	Shrubs
Llanganuco	PC23Loc1Alt3	0214438	8998480	4290	Shrubs
Llanganuco	PC24Loc1Alt3	0214394	8998309	4305	Polylepis forest
Llanganuco	PC25Loc1Alt3	0214511	8998276	4301	Shrubs
Llanganuco	PC26Loc1Alt3	0214409	8998758	4337	Puna
Llanganuco	PC27Loc1Alt3	0214513	8998813	4386	Shrubs
Llanganuco	PC28Loc1Alt3	0214339	8999005	4427	Polylepis forest
Llanganuco	PC29Loc1Alt3	0214452	8999110	4479	Shrubs
Llanganuco	PC30Loc1Alt3	0214271	8999346	4513	Puna
Llaca	PC11Loc2Alt2	0229095	8952121	4008	Polylepis forest
Llaca	PC12Loc2Alt2	0229126	8952165	4007	Shrubs
Llaca	PC13Loc2Alt2	0229240	8952316	4030	Polylepis forest
Llaca	PC14Loc2Alt2	0229224	8952508	4042	Polylepis forest
Llaca	PC15Loc2Alt2	0229295	8952665	4040	Polylepis forest
Llaca	PC16Loc2Alt2	0229367	8952768	4040	Shrubs
Llaca	PC17Loc2Alt2	0229413	8952894	4084	Polylepis forest

Glacial Valley	Point Count IDD	Longitude	Latitude	Elevation (m)	Ecosystem
Llaca	PC18Loc2Alt2	0229569	8953066	4056	Shrubs
Llaca	PC19Loc2Alt2	0229802	8953224	4167	Polylepis forest
Llaca	PC20Loc2Alt2	0229905	8953263	4198	Polylepis forest
Llaca	PC21Loc2Alt3	0230959	8955530	4410	Polylepis forest
Llaca	PC22Loc2Alt3	0231019	8955511	4373	Shrubs
Llaca	PC23Loc2Alt3	0231322	8955493	4383	Shrubs
Llaca	PC24Loc2Alt3	0231674	8955646	4466	Polylepis forest
Llaca	PC25Loc2Alt3	0231517	8955643	4471	Polylepis forest
Llaca	PC26Loc2Alt3	0231260	8955928	4446	Polylepis forest
Llaca	PC27Loc2Alt3	0231401	8956133	4509	Polylepis forest
Llaca	PC28Loc2Alt3	0231574	8956333	4579	Polylepis forest
Llaca	PC29Loc2Alt3	0231643	8956521	4575	Polylepis forest
Llaca	PC30Loc2Alt3	0231708	8956681	4610	Puna
Ulta	PC1Loc3Alt1	0214507	8982766	3515	Shrubs
Ulta	PC2Loc3Alt1	0214682	8983020	3525	Shrubs
Ulta	PC3Loc3Alt1	0214834	8983243	3540	Polylepis forest
Ulta	PC4Loc3Alt1	0215041	8983404	3555	Eucaliptus
Ulta	PC5Loc3Alt1	0215261	8983577	3588	Eucaliptus
Ulta	PC6Loc3Alt1	0215700	8984025	3664	Eucaliptus
Ulta	PC7Loc3Alt1	0215549	8984073	3650	Shrubs
Ulta	PC8Loc3Alt1	0215829	8984260	3655	Polylepis forest
Ulta	PC9Loc3Alt1	0216003	8984692	3667	Shrubs
Ulta	PC10Loc3Alt1	0216070	8984925	3687	Shrubs
Ulta	PC11Loc3Alt2	0221252	8990461	3983	Shrubs
Ulta	PC12Loc3Alt2	0221050	8990539	4003	Shrubs
Ulta	PC13Loc3Alt2	0220840	8990583	4043	Shrubs
Ulta	PC14Loc3Alt2	0220735	8990601	4085	Polylepis forest
Ulta	PC15Loc3Alt2	0220646	8990615	4120	Polylepis forest
Ulta	PC16Loc3Alt2	0220475	8990638	4178	Shrubs
Ulta	PC17Loc3Alt2	0220389	8990560	4159	Shrubs
Ulta	PC18Loc3Alt2	0220282	8990679	4205	Polylepis forest
Ulta	PC19Loc3Alt2	0220240	8990306	4198	Shrubs
Ulta	PC20Loc3Alt2	0220408	8990205	4230	Shrubs
Ulta	PC21Loc3Alt3	0219993	8990282	4258	Polylepis forest
Ulta	PC22Loc3Alt3	0219909	8990222	4260	Polylepis forest
Ulta	PC23Loc3Alt3	0219674	8990291	4297	Shrubs
Ulta	PC24Loc3Alt3	0219473	8990367	4324	Polylepis forest
Ulta	PC25Loc3Alt3	0219453	8990623	4326	Puna
Ulta	PC26Loc3Alt3	0219610	8990686	4371	Polylepis forest
Ulta	PC27Loc3Alt3	0219643	8990841	4400	Puna
Ulta	PC28Loc3Alt3	0219677	8991193	4439	Polylepis forest

Glacial Valley	Point Count IDD	Longitude	Latitude	Elevation (m)	Ecosystem
Ulta	PC29Loc3Alt3	0219773	8991146	4495	Polylepis forest
Ulta	PC30Loc3Alt3	0219761	8991292	4484	Polylepis forest
Rajucolta	PC11Loc4Alt2	0234933	8943551	3965	Shrubs
Rajucolta	PC12Loc4Alt2	0235237	8943600	3982	Shrubs
Rajucolta	PC13Loc4Alt2	0235643	8943677	4006	Shrubs
Rajucolta	PC14Loc4Alt2	0235922	8943638	4021	Shrubs
Rajucolta	PC15Loc4Alt2	0236330	8943470	4054	Polylepis forest
Rajucolta	PC16Loc4Alt2	0236399	8943413	4075	Polylepis forest
Rajucolta	PC17Loc4Alt2	0236571	8943467	4067	Polylepis forest
Rajucolta	PC18Loc4Alt2	0236817	8943685	4078	Shrubs
Rajucolta	PC19Loc4Alt2	0237071	8943665	4105	Shrubs
Rajucolta	PC20Loc4Alt2	0237249	8943747	4115	Shrubs
Rajucolta	PC21Loc4Alt3	0237004	8943882	4182	Polylepis forest
Rajucolta	PC22Loc4Alt3	0237014	8943986	4252	Polylepis forest
Rajucolta	PC23Loc4Alt3	0237001	8944092	4314	Polylepis forest
Rajucolta	PC24Loc4Alt3	0237010	8944227	4389	Polylepis forest
Rajucolta	PC25Loc4Alt3	0237056	8944434	4432	Polylepis forest
Rajucolta	PC26Loc4Alt3	0237067	8944584	4498	Polylepis forest
Rajucolta	PC27Loc4Alt3	0237064	8944645	4533	Polylepis forest
Rajucolta	PC28Loc4Alt3	0237073	8944760	4589	Polylepis forest
Rajucolta	PC29Loc4Alt3	0237032	8944823	4651	Polylepis forest
Rajucolta	PC30Loc4Alt3	0237038	8944949	4678	Puna
Parón	PC1Loc5Alt1	0199351	8999685	3302	Eucaliptus
Parón	PC2Loc5Alt1	0199709	8999847	3358	Eucaliptus
Parón	PC3Loc5Alt1	0199853	9000039	3420	Shrubs
Parón	PC4Loc5Alt1	0200208	9000557	3485	Shrubs
Parón	PC5Loc5Alt1	0200402	9000768	3539	Polylepis forest
Parón	PC6Loc5Alt1	0200615	9001024	3621	Shrubs
Parón	PC7Loc5Alt1	0200883	9001179	3661	Polylepis forest
Parón	PC8Loc5Alt1	0201131	9001330	3707	Polylepis forest
Parón	PC9Loc5Alt1	0201402	9001495	3736	Polylepis forest
Parón	PC10Loc5Alt1	0201709	9001653	3789	Polylepis forest
Parón	PC11Loc5Alt2	0201946	9001918	3880	Shrubs
Parón	PC12Loc5Alt2	0202269	9002130	3900	Polylepis forest
Parón	PC13Loc5Alt2	0202415	9002347	3923	Shrubs
Parón	PC14Loc5Alt2	0202781	9002664	3944	Shrubs
Parón	PC15Loc5Alt2	0203263	9002687	3975	Polylepis forest
Parón	PC16Loc5Alt2	0203615	9002833	4000	Polylepis forest
Parón	PC17Loc5Alt2	0203917	9002965	4058	Shrubs
Parón	PC18Loc5Alt2	0204194	9003251	4104	Shrubs
Parón	PC19Loc5Alt2	0204473	9003287	4139	Shrubs

Glacial Valley	Point Count IDD	Longitude	Latitude	Elevation (m)	Ecosystem
Parón	PC20Loc5Alt2	0204541	9003174	4185	Shrubs
Parón	PC21Loc5Alt3	0207944	9005781	4169	Shrubs
Parón	PC22Loc5Alt3	0208270	9005842	4185	Shrubs
Parón	PC23Loc5Alt3	0208514	9006006	4217	Polylepis forest
Parón	PC24Loc5Alt3	0208689	9006228	4223	Polylepis forest
Parón	PC25Loc5Alt3	0208837	9006441	4280	Polylepis forest
Parón	PC26Loc5Alt3	0208881	9006567	4334	Shrubs
Parón	PC27Loc5Alt3	0208910	9006820	4411	Puna
Parón	PC28Loc5Alt3	0208917	9007107	4473	Polylepis forest
Parón	PC29Loc5Alt3	0208903	9007399	4541	Polylepis forest
Parón	PC30Loc5Alt3	0208831	9007496	4591	Puna

Ash-breasted Tit-tyrant (*Anairetes alpinus*)
Endangered (EN)
Ilustrator: Katty Sandoval